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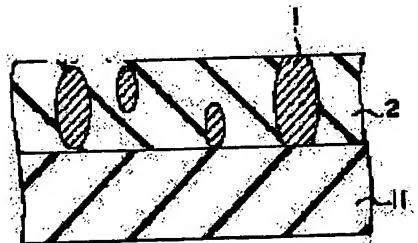
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(54) MAGNETIC RECORDING MEDIUM AND MAGNETIC RECORDING AND REPRODUCING DEVICE

(57)Abstract:
PURPOSE: To obtain a magnetic recording medium capable of high density recording.
CONSTITUTION: This magnetic recording medium has a magnetic thin film consisting of magnetic metal particles 1 and a nonmagnetic matrix 2 whose hardness is higher than that of the particles 1. The particles 1 have shape magnetic anisotropy and crystal magnetic anisotropy and the magnetic metal content of central parts between the particles 1 in the matrix 2 is ≤ 20at.%.



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CLAIMS

[Claim(s)]

[Claim 1] The magnetic-recording medium which the degree of hardness of said nonmagnetic base material is larger than the degree of hardness of said magnetic metal particles, and said magnetic metal particles have magnetic shape anisotropy and a crystal magnetic anisotropy in the magnetic-recording medium which has the magnetic thin film which consists of magnetic metal particles and a nonmagnetic base material, and is characterized by the content of the magnetic metallic element of the center section between said magnetic metal particles in said nonmagnetic base material being below 20 atom %.

[Claim 2] The magnetic-recording medium according to claim 1 whose content of the configuration element of said nonmagnetic base material in the center section of said magnetic metal particles is below 20 atom %.

[Claim 3] The magnetic-recording medium according to claim 1 by which said magnetic metal particles consist of at least one chosen from Co, Pt, Sm, Fe, nickel, Cr, Mn, Bi, aluminum, and the group that consists of these alloys.

[Claim 4] The magnetic-recording medium according to claim 1 by which said nonmagnetic base material consists of an allotrope of the compound expressed with general formula M-G (at least one chosen from the group which M becomes from Si, aluminum, Zr, Ti, and B, and at least one chosen from the group which G becomes from oxygen, nitrogen, and carbon), or carbon.

[Claim 5] The magnetic-recording medium according to claim 1 whose filling factor to said nonmagnetic base material of said magnetic metal particles is 0.7 or less.

[Claim 6] The magnetic-recording medium according to claim 1 from which the filling factor of said magnetic metal particles is changing along the direction of thickness of said magnetic thin film.

[Claim 7] The magnetic-recording medium according to claim 1 whose mean particle diameter in the film surface of said magnetic metal particles is 1/10 or less [of the average size of the magnetic cluster when carrying out alternating current demagnetization].

[Claim 8] The magnetic-recording medium according to claim 1 whose electrical resistivity of said magnetic thin film is 10 to 4 or more ohm-cm.

[Claim 9] The magnetic-recording medium which has the magnetic thin film which consists of magnetic metal particles and a nonmagnetic base material, It is a magnetic recorder and reproducing device possessing the magnetic head which reproduces the signal from said magnetic-recording medium using the resistance change by the field. Said magnetic-recording medium The magnetic recorder and reproducing device whose content of the magnetic metallic element of the center section between said magnetic metal particles [in / the degree of hardness of said nonmagnetic base material is larger than the degree of hardness of said magnetic metal particles, and said magnetic metal particles have magnetic shape anisotropy and a crystal magnetic anisotropy, and / said nonmagnetic base material] is below 20 atom %.

[Claim 10] The magnetic recorder and reproducing device according to claim 9 with which said magnetic-recording medium is used in the condition of contacting said magnetic head.

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DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Field of the Invention] This invention relates to the magnetic-recording medium used with a magnetic tape, a magnetic disk, etc.

[0002]

[Description of the Prior Art] Especially in a hard disk application, record and the ability to regenerate of high density have come to be required more from a magnetic-recording medium with high-performance-izing of a computer in recent years. In order to fill this demand, in current, the thin film of magnetic metals, such as large CoPt of saturation magnetization Is, is used for the record layer. However, since they are inferior to a mechanical strength, these magnetic metal thin films prepare a hard protective layer on a magnetic metal thin film, to the upper part, maintain a very small gap and are surfacing record and the reproducing head so that breakage may not arise at the time of the collision with record and the reproducing head. In addition, as a protective layer, it is SiO₂ whose Vickers hardness in a bulk condition is 2GPa(s). The thin film is used.

[0003] By the way, on the principle of magnetic recording, the more recording density turns into high density, it is necessary to, make small distance (spacing) of record and the reproducing head, and a record layer the more. However, since it will become the limit to reduction of a spacing if a protective layer is prepared, it has been a serious failure for the densification of a magnetic-recording medium. Then, although efforts to prepare a very thin protective layer and make the flying height of a head small are made, when the protection engine performance of such a protective layer is low, the probability of breakage of the magnetic metal thin film by contact on a head will increase on the contrary. Although a thinner protective layer with the high protection engine performance is being recently developed using a carbon thin film etc., as long as a protective layer is prepared anyway, it does not become an essential solution over densification.

[0004] Then, although it can consider making the degree of hardness of the magnetic thin film itself increase using a hard oxide magnetic compact, since the value of magnetization of the oxide magnetic compact known now is small, even if it loses a protective layer, it is not suitable for high density record.

[0005] In addition, in order to realize high density record, it is necessary to fully divide the magnetic interaction between crystal grain in a magnetic thin film. Moreover, since stress arising inside a magnetic thin film and affecting adhesion, magnetic properties, etc. of a magnetic thin film is known when forming a magnetic thin film on a substrate generally, it is necessary to ease stress.

[0006] Although the thing using the magnetic-reluctance (MR) component as the magnetic head of high sensitivity is furthermore developed in recent years, when an MR head and a magnetic thin film contact and there is an electric flow, there is a possibility that a high current may flow for MR component and a head may be damaged. On the other hand, when a magnetic thin film is an insulator, the charge generated by friction with air etc. is accumulated on a magnetic thin film, the discharge to a component from there takes place, and there is a possibility that a head may be damaged by this. In order to avoid such a phenomenon, it is desirable to set it as the value to which the electrical resistivity of a magnetic thin film suited a configuration, an ingredient, etc. of a magnetic recording medium. However, the present condition is that the magnetic-recording medium suitable for the high density record with which are satisfied of these all is not obtained.

[0007]

[Problem(s) to be Solved by the Invention] It is made in order that this invention may solve the above-mentioned trouble, and it aims at offering the magnetic-recording medium in which high density record is possible.

[0008]

[Means for Solving the Problem] In the magnetic-recording medium which has the magnetic thin film which consists of magnetic metal particles and a nonmagnetic base material, the degree of hardness of this invention of said nonmagnetic base material is larger than the degree of hardness of said magnetic metal particles, said magnetic metal particles have magnetic shape anisotropy and a crystal magnetic anisotropy, and the magnetic-recording medium characterized by the content of the magnetic metallic element of the center section between said magnetic metal particles in said nonmagnetic base material being below 20 atom % is offered.

[0009] In the magnetic-recording medium of this invention, according to the information according to a magnetic-recording system, it is magnetized in the predetermined direction, and longitudinal record, slanting record, or vertical recording is possible for magnetic metal particles. Moreover, the magnetic-recording medium of this invention is applicable to both the method with which record and a regenerative apparatus (head) contact a magnetic-recording medium, and the method with which a head surfaces from a magnetic-recording medium.

[0010] It is made for magnetic metal particles to have magnetic shape anisotropy and a crystal magnetic anisotropy in the magnetic-recording medium of this invention. Or for magnetic metal particles, magnetic-shape-anisotropy energy is 104 J/m³. It is 5x104 J/m³ preferably above. It is above and crystal anisotropy energy is 5x105 J/m³. It is 106 J/m³ preferably above. It is made to be above.

[0011] Here, magnetic shape anisotropy and a crystal magnetic anisotropy are explained briefly. A magnetic anisotropy is the property in which a magnetic property changes with directions of objective, and it is the *** magnetic anisotropy which what the cause of the different property depends on the configuration of the magnetic substance depends on magnetic shape anisotropy and the crystal structure. For example, since it is easy to be magnetized in the direction of a major axis, the needlelike magnetic substance has magnetic shape anisotropy. Moreover, since a certain specific direction (C shaft) of [on the crystal structure] is easy to be magnetized, Co has a crystal magnetic anisotropy. Moreover, the difference of energy required to turn magnetization in the direction which is easy to be magnetized, and the difficult direction is anisotropy energy, and magnetization can be stabilized and turned in a certain direction, so that this energy is large. Moreover, if anisotropy energy is large, it will be stabilized, and the recorded information can be held and magnetic properties desirable for the magnetic-recording medium of being able to enlarge a signal output will be acquired.

[0012] In the magnetic-recording medium of this invention, it can consider as perpendicular magnetic anisotropy films by giving magnetic shape anisotropy in the direction of thickness using what has a long and slender configuration in the direction of thickness in magnetic metal particles, for example. Moreover, it can consider as perpendicular magnetic anisotropy films similarly by using Co radical alloy for magnetic metal particles, and making it grow up so that C shaft of a crystal may be suitable in the direction of thickness. When magnetic metal particles have both magnetic shape anisotropy and a crystal magnetic anisotropy, a bigger perpendicular magnetic anisotropy can be given to a magnetic thin film, and it can apply to any magnetic-recording medium a perpendicular, slant, and for longitudinal record. For example, when the magnetic metal particles which consist of a Co radical alloy have the configuration of ** length in the direction of thickness and C shaft of a crystal is growing along the direction of thickness, a bigger magnetic anisotropy can be acquired according to the synergistic effect of two magnetic anisotropies. In this case, coercive force can be enlarged and it comes to be able to perform higher-density record with a small record magnetic domain.

[0013] It is said that the direction which has a certain amount of perpendicular magnetic anisotropy is suitable for high density record in the case of the medium for longitudinal record, and this can be realized when the magnetic metal particles C shaft is carrying out [metal particles] orientation to for example, film surface inboard have a long and slender configuration in the direction of thickness. In addition, since the origins differ, it is easy to control magnetic shape anisotropy and a crystal magnetic anisotropy in respect of a medium production process, ingredient selection, etc. independently. Therefore, it can be said that it is desirable for the magnetic-recording medium of high density to provide these two magnetic anisotropies. In addition, the magnitude and the sense of a magnetic anisotropy are determined by the ingredient which constitutes a magnetic-recording medium, production equipment, the specification required of a drive.

[0014] The magnetic-recording medium of this invention consists of magnetic thin films which consist of magnetic metal particles held in the nonmagnetic base material at the nonmagnetic base material list which continues and exists in the direction of thickness, and film surface inboard. That a nonmagnetic base material continues and exists in the direction of thickness and film surface inboard of a magnetic thin film means that a nonmagnetic base material has network-like structure. The nonmagnetic base material in this invention is bearing the role which the mechanical strength of the whole magnetic thin film is raised, and raises electrical resistivity, and divides the magnetic interaction between magnetic metal particles.

[0015] As magnetic metal particles, the thing with large and saturation magnetization Is which has a large magnetic

anisotropy is desirable. As such a thing, Co, Pt, Sm, Fe, nickel, Cr, Mn, Bi, aluminum, or these alloys can be used. It is desirable to use Mn alloys, such as Co radical alloys, such as CoPt, SmCo, CoCr, etc. which have a big crystal magnetic anisotropy especially, and MnBi, MnAl which have large anisotropy energy. Moreover, Fe and/or nickel may be added in order to control magnetic properties into these metals or alloys. Furthermore, in order to raise magnetic properties into these metals or alloys, Cr, Nb, V, Ta, Ti, W, Hf, In, Si, B, etc. may be added.

[0016] Although the configuration of magnetic metal particles may be spherical, in order to raise magnetic shape anisotropy, cylindrical, a spheroid configuration, etc. are sufficient as it. Magnetic metal particles are magnetized according to the information recorded towards desired (for example, a direction perpendicular to the inside of the field on the front face of a medium, and a medium front face or its middle direction), and, thereby, information is recorded. If magnetic metal particles are arranged so that the direction of a major axis may incline to the field inboard of a magnetic-recording medium front face, it will be easy to be magnetized in a field, and if it arranges so that it may incline in the perpendicular direction to a magnetic-recording medium front face, it will become is easy to be magnetized gradually perpendicularly.

[0017] Although it is generally difficult to determine correctly the physical property which a magnetic-recording medium should fulfill in order to attain the purpose of preventing the damage on when the magnetic head contacting a magnetic-recording medium, a degree of hardness is employable as one criteria. Theoretically, it is thought that damage on the magnetic-recording medium by contact to the magnetic head becomes small, so that a degree of hardness is large.

[0018] From such a viewpoint, what has high resistivity is used by the high degree of hardness in the state of bulk as a nonmagnetic base material. Even if it thin-film-izes a hard ingredient with bulk, sufficient degree of hardness is kept general. As an ingredient of such a nonmagnetic base material, the compound expressed for example, with general formula M-G is mentioned. M is at least one sort chosen from the group which consists of Si, aluminum, Zr, Ti, In, Sn, and B here, and G is at least one sort chosen from the group which consists of oxygen, nitrogen, and carbon. Specifically, Si-O, aluminum-O, Zr-O, Ti-O, Si-N, aluminum-N, Zr-N, Ti-N, B-N, Si-C, Ti-C, B-C, SiAl-ON, Si-ON, AlTi-OC, In-Sn-O, etc. are desirable. Moreover, as an ingredient of a nonmagnetic base material, it excels in lubricity and diamond[the allotrope of the carbon which is a high degree of hardness in the state of bulk, for example, a diamond, amorphous carbon, and]-like carbon etc. can also be used. The degree of hardness in the bulk of the ingredient which constitutes these nonmagnetic base materials is SiO₂ of bulk. It is desirable comparable as Vickers hardness 2GPa which it has, or that it is more than it. Furthermore, it is possible to make high sharply electrical resistivity of the whole magnetic-recording medium compared with a metal thin film medium by using the ingredient which consists of an electric insulator or a semi-conductor as an ingredient of a nonmagnetic base material.

[0019] Moreover, in order to raise the degree of hardness and abrasion resistance of a nonmagnetic base material, a nonmagnetic element may be added into the above-mentioned ingredient. In this case, the alloying element may be dissolving in a nonmagnetic base material, and where phase separation is carried out, it may be added. Moreover, the alloying element may exist in a nonmagnetic base material in the state of a particle. The condition that an alloying element exists is suitably chosen with the mechanical property and magnetic property of a magnetic thin film in the condition that magnetic metal particles are distributed.

[0020] When the magnetic thin film in this invention adds an alloying element which was mentioned above for the improvement in a property of magnetic metal particles and a nonmagnetic base material, the same element as magnetic metal particles and a nonmagnetic base material may be added. Moreover, since it is impossible to form the bipolar membrane in the condition that magnetic metal particles and a nonmagnetic base material were completely separated on atomic level as a matter of fact so that it may mention later, the alloying element to magnetic metal particles may exist in a nonmagnetic base material. In this case, in order to demonstrate the effectiveness of an alloying element more efficiently, the alloying element in a nonmagnetic base material should just be 1/100 or less rate more preferably 1/10 or less compared with the inside of magnetic metal particles. Even if this relation replaces a nonmagnetic base material and magnetic metal particles, it is realized.

[0021] A metal, glass, a ceramic, etc. can be used as a substrate which supports the magnetic thin film which consists of magnetic metal particles and a nonmagnetic base material. In addition, the substrate layer which consists of the magnetic substance or non-magnetic material may be prepared between a substrate and a magnetic thin film. In using a metal substrate especially, in order to prevent the short circuit between the magnetic head and a magnetic-recording medium, it is desirable to use the substrate layer which has electric insulation. Moreover, a very thin (100A or less) protective coat may be prepared in the front face of a magnetic-recording medium if needed. Furthermore, as for magnetic metal particles, it is desirable to keep the distance (1nm or more) which is extent which magnetic exchange force does not attain to, and to be held at the nonmagnetic base material. This is for it not only raising electric resistance,

but raising the coercive force of a magnetic-recording medium and reducing the noise of a magnetic-recording medium. [0022] The substrate layer which consists of the magnetic substance is magnetically combined by the magnetic domain in a magnetic thin film, record/playback head, and an exchange interaction and a static magnetism interaction, in order to perform efficient record/playback to a magnetic thin film. When arranging a substrate layer so that switched connection may be carried out to a magnetic domain, the approach of stabilizing a magnetic domain using the substrate layer which consists of the magnetic substance which is easy to carry out flux reversal, or the approach to which a playback output is made to increase using the substrate layer which consists of the big magnetic substance of magnetization is mentioned.

[0023] The substrate layer which consists of non-magnetic material is arranged in order to prevent mixing of the impurity from the purpose which controls the crystal structure of magnetic metal particles or a nonmagnetic base material, or a substrate. For example, it is possible to control the lattice spacing of the crystal of magnetic metal particles by using the substrate layer which consists of an ingredient with the lattice spacing near the lattice spacing of the crystal structure of a request of magnetic metal particles. Moreover, the crystallinity of magnetic metal particles or a nonmagnetic base material or amorphous nature may be controlled by, for example, using the amorphous substrate layer which has a certain surface energy. Moreover, what is necessary is just to use the small thin film or the precise thin film of a lattice spacing as a substrate layer, in preventing mixing of the impurity from a substrate. The substrate layer which consists of a substrate layer which consists of the above-mentioned magnetic substance, or non-magnetic material may have the function which another side has. That is, you may have the property that the substrate layer which consists of the magnetic substance controls the crystallinity of magnetic metal particles. In this case, since the effectiveness on record/reproducing characteristics and crystalline effectiveness are multiplied, it is more desirable. Moreover, the above-mentioned substrate layer may be formed by reforming the front face of a substrate by doping in ion plating and a controlled atmosphere, neutron beam exposure, etc. According to these approaches, since a film formation process is not minded, it is desirable on medium production.

[0024] In the magnetic-recording medium of this invention, the volume phase for combining magnetic metal particles and a nonmagnetic base material efficiently between magnetic metal particles and a nonmagnetic base material, or preventing the counter diffusion of the configuration element of magnetic metal particles and a nonmagnetic base material may exist. The element which constitutes at least magnetic metal particles or a nonmagnetic base material either may exist in this volume phase as a principal component, and the element which constitutes magnetic metal particles and a nonmagnetic base material hardly needs to exist in it. In the case of the former, it is desirable at the point of combining magnetic metal particles and a nonmagnetic base material firmly mechanically, and the latter is desirable at the point of separating magnetic metal particles and a nonmagnetic base material completely magnetically.

[0025] The magnetic thin film in this invention is formed by making a magnetic metallic material and a non-magnetic material deposit on a substrate with physical vapor deposition or chemical vapor deposition into a vacuum. The approach shown below is mentioned as physical vapor deposition. (a) Use the target of a magnetic metallic material, and the target of a non-magnetic material, and it is coincidence sputtering. (b) Coincidence sputtering in the inert gas ambient atmosphere which contains oxygen, nitrogen, or carbon using TA 1 get of two or more metallic materials.

[0026] In this case, the nonmagnetic base material which consists of a compound with some metals, oxygen and nitrogen, or carbon is formed. In addition, the multicomponent target which in (a) and (b) the ingredient of magnetic metal particles and a nonmagnetic base material may be arranged by the respectively separate target, and has arranged both ingredients at the same target is sufficient. It is in the advantage of tending to respond to aging of a magnetic property or a mechanical property in the case of the former, and, in the case of the latter, there is an advantage of being suitable for mass production method.

[0027] Namely, it is known for these thin film formation approaches that a crystal will generally grow in the shape of a column. Therefore, both magnetic metal particles and a nonmagnetic base material can be grown up in the shape of a column by choosing process parameters, such as a class of injection power, a sputtering pressure, a reactant type of gas, a membrane formation rate, bias power, and additive. Moreover, in the thin film formation by the sputtering method, generally, a magnetic metal tends to grow in the shape of a column, and it is easy to make a hard dielectric thin film amorphous. It becomes possible to obtain from this the magnetic thin film which the magnetic metal particles of the shape of a big column of magnetic shape anisotropy mixed into the nonmagnetic base material which consists of a hard dielectric made amorphous by growing up a magnetic metal and hard dielectric materials into coincidence by the sputtering method.

[0028] Although it is given in the direction of thickness of a magnetic thin film when magnetic metal particles grow in the shape of [with the long and slender magnetic shape anisotropy of magnetic metal particles] a column at this time, depending on the condition of crystal growth, cylinder-like crystal grain may turn that medial axis to film surface

inboard, and may grow. In that case, magnetic shape anisotropy will be given to film surface inboard. Moreover, the sense of a crystal magnetic anisotropy is decided by in which direction of the direction of thickness / film surface inboard the crystallographic axis which has an anisotropy is suitable. This can be controlled by the condition of crystal growth. As a process parameter which affects the condition of crystal growth, the class of above-mentioned injection power, a sputtering pressure, a reactant type of gas, a membrane formation rate, bias power, and additive etc. is mentioned. In addition, since the condition of a substrate and the condition of membrane formation of the substrate film, for example, crystal orientation, surface energy, etc. affect a magnetic anisotropy, a predetermined magnetic anisotropy can be acquired also by choosing these parameters.

[0029] Moreover, as chemical vapor deposition, MOCVD, plasma CVD, plural coincidence vacuum evaporationo, etc. are mentioned. In these approaches, it may heat-treat into the ingredient deposited on the substrate if needed, and magnetic metal particles may be deposited in a nonmagnetic base material.

[0030] In case a magnetic thin film is formed on a substrate, the short circuit between the magnetic heads can be more completely prevented by magnetic metal particles' making a ***** rate small by the medium front-face side at a nonmagnetic base material, and enlarging the rate by the substrate interface side. Medium magnetic field strength can be raised by enlarging the above-mentioned rate and making it small by the substrate interface side by the medium front-face side, on the contrary. In addition, the rate and distribution condition of magnetic metal particles in a nonmagnetic base material can be chosen by changing membrane formation conditions, such as a power ratio supplied to the target of a magnetic metallic material, and the target of a non-magnetic material.

[0031] The magnetic-recording medium of this invention has the description as shown below to the conventional magnetic-recording medium.

(1) Since a nonmagnetic base material consists of an ingredient of a high degree of hardness, the magnetic-recording medium of dissolution this invention of the spacing loss by the protective layer has mechanical strength with a sufficient magnetic thin film. It becomes unnecessary for this reason, to prepare the indispensable protective layer by the conventional magnetic-recording medium. Although the spacing which is the distance between record / playback head and a magnetic thin film was conventionally completed only more than protection layer thickness, by the magnetic-recording medium by this invention, this limit of it is completely lost. When a spacing is made small, and it means that the impossible high density record is attained conventionally and it considers as recording density comparable as the former, this can enlarge distance of a magnetic-recording medium and a head, and means that the damage probability of a head or a medium can be reduced sharply. Furthermore, since the process which produces a protective layer becomes unnecessary, the yield of medium production can improve and the manufacturing cost of a medium can be lowered. In addition, when a magnetic thin film does not have sufficient degree of hardness to be equal to actuation in the condition that there is no protective layer, or when carrying out usage which cannot bear even by the medium with [, such as contact actuation,] the conventional protective layer, a protective layer may be prepared on the magnetic thin film by this invention. In this case, since the degree of hardness of the magnetic thin film itself is large to the conventional metal thin film, it is easy to produce a protective layer.

(2) By the magnetic-recording medium of reduction this invention of a medium noise, a nonmagnetic base material exists between each magnetic metal particles, and since the distance between magnetic metal particles is larger than the distance which an exchange interaction attains to, a medium noise can be made small.

[0032] Although informational record is performed by forming a reversal magnetic domain on a magnetic-recording medium, this reversal magnetic domain consists of crystal grain of a magnetic thin film further. Within crystal grain, the spin of each atom has turned to the same direction, and reverses it to coincidence mostly within crystal grain by the field from a head. Therefore, ideally, the granularity of the boundary of a reversal magnetic domain is magnitude extent of crystal grain, and causes a record noise produced when the granularity of this boundary records information. In a magnetic thin film, although non-magnetic material, such as an oxide, generally exists between the crystal grain of the magnetic substance, an exchange interaction works between crystal grain that the insulation with it is inadequate. [a short distance between crystal grain and] [magnetic] In such the condition, if one crystal grain carries out flux reversal, flux reversal also of the crystal grain which adjoins by the exchange interaction will be carried out, and the unit of flux reversal will serve as some crystal grain groups. In this case, the boundary of a reversal magnetic domain will become coarser and will be generated in a big medium noise. The conventional magnetic-recording medium is afflicted by this problem, and although to add various additives into a medium ingredient is tried, it has not divided the interaction between crystal grain completely. Although between crystal grain can be detached to about 1nm the place by the present, an insulation magnetic for diffusion of a magnetic element etc. is not perfect, and the record noise of a number - 10dB of numbers has generated it. On the other hand, there is no title in the magnetic-recording medium of this invention in the meantime. That is, since between magnetic crystal grain is completely insulated by the nonmagnetic

base material, an exchange interaction is very small.

(3) In using the magneto-resistive effect (MR) mold head of the controllability high sensitivity of the resistivity of a medium, the resistivity of a magnetic-recording medium becomes a problem. That is, when destruction of record / playback component by discharge between medium 1 heads or a medium poses a problem, the one where the electrical conductivity of a magnetic-recording medium is higher is desirable. Moreover, it is more desirable for a magnetic-recording medium to be insulation when the destruction of MR component and the fall of signal strength by current leak to a medium pose a problem.

[0033] The configuration of the conventional magnetic-recording medium was a configuration that the insulating protective layer was formed on the metal thin film, and cannot control electrical resistivity of the whole magnetic-recording medium, without spoiling magnetic properties and the protection engine performance. However, the magnetic-recording medium by this invention is the mixture of magnetic metal particles and a nonmagnetic base material, and can control electrical resistivity by a class, an amount, etc. of both mixing ratio or an additive to arbitration.

[0034] Moreover, the magnetic thin film which comes to distribute a magnetic metal particle in a dielectric is proposed as an approach of solving the above-mentioned trouble which the conventional **** thin film medium has (USP4,973,525). However, on the substrate heated to 700-800K, it is only indicated that it is necessary to produce by sputtering, and it is not said at an acquiring [this magnetic thin film]-to magnetic-recording medium-usable magnetic properties sake how big anisotropy energy is obtained. It is difficult for especially Fe particle currently mentioned as the example it to be known for that crystal anisotropy energy is a quite small ingredient, and for a configuration to also acquire coercive force required for near and a magnetic-recording medium to a globular form. Although it is indicated by the example that the coercive force of 1kOc extent is acquired, this is considered that induction was carried out by the stress by heat treatment etc. In this case, exfoliation of the film by stress may pose a problem, and heat treatment temperature called 700-800K may give a damage to a substrate. On the other hand, since magnetic metal particles have both magnetic shape anisotropy and a crystal magnetic anisotropy, the magnetic-recording medium of this invention can acquire big coercive force. Moreover, since heat treatment is not needed, there is also no damage given to a substrate.

[0035] Here, the example of the magnetic-recording medium of this invention is explained with reference to drawing 1 and drawing 2. In drawing 1, the magnetic thin film which consists of a nonmagnetic base material 2 which exists succeeding the magnetic metal particles 1, the direction of thickness, and film surface inboard which have magnetic shape anisotropy and a crystal magnetic anisotropy is formed on the glass substrate 11.

[0036] Moreover, in drawing 2, the substrate layer 12 is formed on a glass substrate 11, and the magnetic thin film which consists of magnetic metal particles 1 which have magnetic shape anisotropy and a crystal magnetic anisotropy, and a nonmagnetic base material 2 which exists succeeding the direction of thickness and film surface inboard is further formed on it. Here, as for the thickness of such a magnetic thin film, it is desirable that they are 100nm or less, 50 morenm or less, and 20 morenm or less. This is because distortion resulting from stress will enter into a magnetic thin film when membrane formation time amount long-duration-izes and the film will become easy to exfoliate, if the thickness of a magnetic thin film is too thick. In addition, when performing longitudinal record, record of high density is attained, so that it is a thin film.

[0037] It can be considered that the magnetic thin film which constitutes the magnetic-recording medium of this invention is the composite material of magnetic metal particles and a nonmagnetic base material. If this magnetic thin film is expressed according to the definition of connectivity of composite material, since the nonmagnetic base material is the integrated state whose magnetic metal particles are breadth and are two-dimensional or one dimension to the three dimension, it can be said that they are the so-called "3-1 Association" or "3-2 association." Such an integrated state is not known for the conventional magnetic-recording medium.

[0038] In the magnetic-recording medium of this invention, it can check that the nonmagnetic base material has become network-like by dipping a magnetic thin film in an acid etc. and fully dissolving only magnetic metal particles. And if a nonmagnetic base material remains on a substrate where the configuration of the original magnetic thin film is maintained even if it removes only magnetic metal particles, the magnetic thin film itself can say that the requirement over robustness is fully satisfied.

[0039] The magnetic-recording medium of this invention has the structure where magnetic metal particles and a nonmagnetic base material carry out phase separation, and are intermingled. However, since diffusion of the atom which constitutes magnetic metal particles after the time of thin film formation or thin film formation, and the atom which constitutes a nonmagnetic base material may take place from a microscopic viewpoint, it is difficult to form the bipolar membrane from which magnetic metal particles and a nonmagnetic base material were completely separated on atomic level. Therefore, in the specific region (center section) of a nonmagnetic base material, in order to acquire the above-

mentioned advantage which the structure where magnetic metal particles and a nonmagnetic base material were separated brings about, or the content of the magnetic element which constitutes magnetic metal particles is below 20 atom %, it is required for the content of the element which constitutes a nonmagnetic base material in a magnetic metal-particles center section to be below 20 atom %.

[0040] Here, the specific region between the magnetic metal particles in the center section and nonmagnetic base material of magnetic metal particles (center section) is explained. Drawing 3 is drawing showing the thin film planar image by the transmission electron microscope (TEM) of the particle distribution thin film at the time of using SiO for the ingredient of a nonmagnetic base material, using a CoPt particle as magnetic metal particles in the configuration shown in drawing 1. 31 in drawing shows the magnetic all group particle section which mainly consists of CoPt, and 32 shows the nonmagnetic base material section which mainly consists of SiO. These parts are clearly distinguishable in a flat-surface TEM image with the discontinuity of a crystal lattice, the discontinuity change section of the contrast of an image, etc.

[0041] Drawing 4 is drawing showing presentation distribution of Si and Co on the A-A line in drawing 3. This detailed component analysis can be obtained to the image and coincidence of drawing 3 by electron diffraction. In drawing 4, the boundary of the magnetic metal-particles section 31 judged from drawing 3 and the nonmagnetic base material section 32 is also shown. In the magnetic-recording medium of this invention, the specific region between the magnetic metal particles in a nonmagnetic base material means the field of 80% of center sections of the field of the nonmagnetic base material section 32 between the magnetic all group particle sections 31 of drawing 4. Moreover, the center section of magnetic metal particles means the field of 80% of center sections of the field of the magnetic all group particle section 31 of drawing 4. Moreover, since a size changes with how to choose the A-A line on a flat surface TEM, as for this field, a multiple-times line opts for the above-mentioned analysis by that average. Therefore, the analysis average will estimate the degree [base material / magnetic metal particles and / nonmagnetic] of distribution.

[0042] Drawing 5 is the same presentation as drawing 3, and is drawing showing a flat-surface TEM image when the volume phase exists between above-mentioned magnetic metal particles and a nonmagnetic base material. 31 in drawing shows the magnetic metal-particles section which mainly consists of CoPt, 32 shows the nonmagnetic base material section which mainly consists of SiO, and 51 is amorphous -- the volume phase which consists of CoO is shown. These parts are clearly distinguishable on a flat surface TEM like the case of drawing 3. Moreover, drawing 6 is drawing showing the result of the presentation part chip box on the B-B line of drawing 5. The magnetic metal-particles center section in the case of drawing 6 is the field of 80% of center sections of the field 31, and the specific region between the magnetic metal particles in a nonmagnetic base material is a field of 80% of center sections of the field 32 between fields 31.

[0043] The magnetic metal atom in a nonmagnetic base material has the operation which strengthens the exchange interaction between magnetic metal particles. The magnitude of attenuation of an exchange interaction to the amount of magnetic elements (Co) of the specific region of the nonmagnetic base material in the example of drawing 3 is shown in drawing 7. This installs a nonmagnetic base material between two magnetic metal particles, and has shown it in the relative amount when setting the magnitude of attenuation of an exchange interaction in case the amount of Co(es) is zero atom % to 1. the time of the amount of Co(es) being 5, 10, and 20 atoms % so that drawing 7 may show -- the magnitude of attenuation -- respectively -- 0.99 and 0. -- it is 97 and 0.95, and if it becomes 50 atom %, it will hardly decrease. The threshold limit value of the magnetic element of the specific region of this to a nonmagnetic base material is 5% or less more preferably 10% or less below 20 atom %. the concentration more than 20 atom % -- diffusion (for example, diffusion into the magnetic metal particles of the oxygen atom in a nonmagnetic base material) of the configuration element between magnetic metal particles and a nonmagnetic base material -- happening -- being easy -- it will lead to degradation of the magnetic properties of the whole magnetic thin film.

[0044] Change of the anisotropy energy to the amount of Si in the center section of the magnetic metal particles in the example of drawing 3 is shown in drawing 8. The relative value set to 1 shows the case where the amount of Si is zero atom %. the time of the amount of Si being 5, 10, and 20 atoms % so that drawing 8 may show -- anisotropy energy -- respectively -- 0.95 and 0. -- it is 90 and 0.80, and it becomes impossible to fully pull out the anisotropy energy which CoPt has, and it becomes impossible to maintain the magnetic properties as a magnetic-recording medium above 20 atom %. The threshold limit value of the configuration element of the nonmagnetic base material in this to a magnetic metal-particles center section is 5% or less more preferably 10% or less below 20 atom %. By the concentration more than 20 atom %, diffusion of the configuration element between magnetic metal particles and a nonmagnetic base material becomes easy to take place, and it will lead to degradation of the magnetic properties of the whole magnetic thin film. In addition, although the above-mentioned elemental analysis is performed in a surfacing field, it is equivalent. [of elemental analysis / in / with the thin film of 100nm or less extent in thickness / a surfacing field / and

the elemental analysis in the direction of thickness]

[0045] In the magnetic-recording medium of this invention, as for the magnetic metal particles with magnetic shape anisotropy, it is common to have different direction physical configurations other than a globular form, and it is desirable that it is the configuration of the shape of a long rod, such as a cylinder and a spheroid, in the direction which wants to produce an anisotropy. Here, the configuration of magnetic metal particles is further explained to a detail. Now, they are N and space permeability about the demagnetization factor about the magnetic particle of the volume v with Magnetization I mu 0 When it carries out, the magnetostatic energy of the direction of N is expressed with $U=1/2\mu_0 N^2 I^2$, and v. If a magnetic particle is axial symmetry about the z-axis, they are the demagnetization factor Nx of x, y, and the direction of the z-axis, Ny, and Nz. It is $Nx = Ny = (1-Nz)/2$. Considering the case where the configuration of a magnetic particle is a spheroid, the magnetostatic energy U when saturation magnetization I is leans at the include angle theta from the z-axis is $U=1/4\mu_0 I^2 \sin^2 \theta / (3Nz - 1)$, and $\cos^2 \theta$. Theta+const

It comes out. This formula shows that the magnitude of magnetic-shape-anisotropy energy is proportional to $(1-3Nz)$. Moreover, it is that it becomes $Nz=0$ and min that magnetic shape anisotropy becomes max at the time of $Nz=1/3$. if (die length of major axis)/(the die length of a minor axis) is set to r along with the z-axis and r and relation with $(1-3Nz)$ are investigated -- r= 1, and 1.5, 2, 3, 5 and 10 -- receiving -- respectively $(1-3Nz) = 0, 0.30, 0.48, 0.67, 0, 0.83$, and 0.94. [of the spheroid of ** length] if this to r is 1.5 or more -- the maximum magnetic shape anisotropy -- further with [r] three [or more], about 70% of magnetic shape anisotropy can be acquired about 30%. moreover, this has the long configuration of magnetic metal particles -- if cylindrical, not only a spheroid but the almost same relation will be satisfied.

[0046] Next, in order to realize high density record using the magnetic-recording medium in this invention, the conditions which a magnetic thin film should fulfill are examined. A filling factor and electrical resistivity are explained among the physical properties of a magnetic thin film below.

(1) The filling factor of the magnetic metal particles in a filling factor nonmagnetic base material does effect important for the degree of hardness of a magnetic thin film, magnetic properties, etc. When it assumes now that magnetic metal particles are cylindrical shapes-like, and the array of the particle seen from the base is hcp, a filling factor p is expressed with the following formulas (I) using the radius a of a particle, and the spacing b between particles.

[0047]

[Equation 1]

$$p = 2\pi a^2 / (\sqrt{3} \cdot (2a + b)^2) \quad \dots (I)$$

[0048] The diameter of crystal grain of the magnetic metal particles of the typical thin film mold magnetic-recording medium used now is about 40nm, and it is known that the distance required in order to divide the exchange interaction between magnetic metal particles is about 1nm at least. If these values are assigned and calculated, 0.7 or less will be the p. Furthermore, it is clear by controlling the filling factor of magnetic metal particles that the degree of fragmentation of the magnetic interaction between magnetic metal particles is controllable. In order to record high density more, as for the value of a filling factor, it is desirable that it is 0.5 or less. However, the value of a filling factor is one of the guides, and the optimum value of p is decided by the specification of a magnetic drive system. Moreover, by the magnetic-recording medium in the magnetic recorder and reproducing device of this invention, since it can consider that magnetic metal particles are the impurities of a nonmagnetic base material, the internal stress of a magnetic thin film is controllable by the filling factor. In addition, even if the array seen from the base of magnetic metal particles is except hcp(s), such as fcc, since it is the same, the exchange interaction of magnetic metal particles is effectively divided with 0.7 or less value of such a filling factor here. Although the average of the filling factor covering the whole magnetic thin film is also controllable as mentioned above, change of a filling factor can carry out along the direction of thickness of a magnetic thin film, a way can be controlled to arbitration, and various properties can also be improved. In addition, although it does not limit, with [especially the minimum of a filling factor] 0.05 [or more], it is enough.

[0049] For example, if it is made to change so that the high part of a filling factor and a low part may appear by turns along the thickness direction of a magnetic thin film, stress can be centralized little by little locally and internal stress can be made to ease as a whole. If the internal stress of a magnetic thin film is eased, since the adhesion of the magnetic thin film to a substrate will improve, the endurance of a magnetic-recording medium and a life can improve and the defect of the magnetic thin film which causes a burst noise further can be decreased. In addition, what is necessary is just to give a suitable change by each case, since change of such a filling factor carries out, a way is an example and the value of internal stress changes with membrane formation conditions of a magnetic thin film.

[0050] Moreover, if it is made to change from a substrate side so that a filling factor may become low toward a

magnetic-thin-film front face, since the degree of hardness of the front face of a magnetic-recording medium will improve, the endurance of the magnetic-recording medium to a head crash etc. can be raised more. In this case, since it has sufficient endurance even if it carries out contact transit and makes a head record, the magnetic-recording medium in which the magnetic recording of high density is very possible is realizable.

[0051] On the contrary, if it is made to change so that a filling factor may increase from a substrate side toward a magnetic-thin-film front face, since the magnetization in the front face of a magnetic thin film will become large, a playback output can be enlarged. Here, since the difference of the mechanical property in the interface of a substrate and a magnetic thin film becomes small when the ingredient of a substrate and a nonmagnetic base material is similar and mechanical properties, such as both expansion coefficient, are similar, adhesion can be raised.

[0052] Furthermore, in contacting a magnetic thin film and the magnetic head and recording them, it becomes an important factor that the degree of hardness and electric insulation in a front face of a magnetic thin film are also high. Therefore, the rate of the magnetic metal particles in the front face of a magnetic thin film is also one of the important parameters. In the front face of a magnetic thin film, it is desirable that the values of (area of magnetic metal particles)/(area of a nonmagnetic base material) are 0.7 or less and further 0.5 or less like the filling factor of magnetic metal particles. Substantially, it is enough if there are 0.05 or more.

(2) If an insulator is used as a nonmagnetic base material, the electrical resistivity of a magnetic thin film is controllable by the magnetic-recording medium of electrical resistivity this invention by controlling the filling factor of magnetic metal particles. Moreover, the electrical resistivity of the whole thin film is controllable by adding an element to a nonmagnetic base material. if the electrical resistivity of a magnetic thin film is 1 or more ohm-cm -- the conductor of a head -- compared with a part, it can fully be regarded as an insulator, and even when an MR head is used, destruction of the head by a current leaking to the medium at the time of contact can be prevented. an MR head -- like -- the conductor of a head -- since resistance of the part increases when the part is made detailed -- the electrical resistivity of a magnetic thin film -- 10⁵ In order for that it is more than omega-cm to maintain desirable still more perfect electric insulation, it is desirable that they are 10¹⁰ or more ohm-cm.

[0053] On the other hand, if a high speed is made to rotate the medium of the shape of a disk which consists of a magnetic-substance thin film on a glass substrate, it is known that a charge will be generated on a disk by friction with atmospheric air. A head component may be destroyed if the charge which accumulated on the disk discharges to a magnetic head. the amount of charges which accumulated -- at least -- the conductor of a magnetic head -- if the volume of a part is small, the current which flows there will become large. Therefore, the charge which accumulates on this disk poses a problem as integration of a head component progresses. When the direction of a charge poses a problem from the above-mentioned insulation, it is desirable to give a certain amount of conductivity to a medium. However, since leak of the current from an above-mentioned head component will occur if it becomes a conductor completely, it is not desirable. Specifically, electrical resistivity is 10-4-10⁵. It is desirable that it is omega-cm. In addition, a certain amount of [insulating and] above-mentioned electrical conductivity is chosen according to the system environment of a head, a magnetic disk drive, etc. to be used. The indium stannic acid ghost (ITO) is known as a base material ingredient which realizes electrical resistivity of 10 to 4 or more ohm-cm. Moreover, as a base material ingredient which realizes electrical resistivity 10-2ohm and more than cm, the nitride of transition metals, such as TiN, TaN, and TiC, is known. What is necessary is just to use the usual dielectric materials, for example, SiO, AlN, BN, etc., in realizing electrical resistivity beyond it.

[0054] The demand to the electrical resistivity of an above-mentioned medium is in the condition of having made it contacting through a head on a magnetic disk drive system, and it is desirable to be filled between a medium substrate or a spindle, and what kind of conductive part in a head. For example, in the condition of having made it contacting through a head when preventing destruction of the head component by static electricity, if electrical resistivity is set as 1 or more ohm-cm between a medium substrate or a spindle, and what kind of conductive part in a head, it will not happen in damage on a head to the bottom of what kind of operating condition. Similarly, in order to prevent leak of the current from an above-mentioned head component, it is desirable to set electrical resistivity as 10 to 4 or more ohm-cm in the condition of having made it contacting through a head, between a medium substrate, or SUBINDORU and what kind of conductive part in a head.

(3) The magnetic-recording medium of magnetic-properties this invention of the whole magnetic thin film is 1 Gb/in². In order to hold a record magnetic domain minute in order to make the above high density magnetic recording possible to stability, the high coercive force Hc is required. Specifically, it is desirable to have Hc of 2 or more kOes. Furthermore, 10 Gb/in² In order to attain the recording density of level, it is desirable to have Hc of 3 or more kOes. Moreover, when it thinks from a head-medium interaction, Hc of a magnetic-recording medium has the close relation to the saturation magnetic flux density Bs of a magnetic-recording head.

[0055] The relation between Bs and magnetization transition width of face (transition length) by the computer simulation in the case of being recording track width-of-face [of 3 micrometers], 0.25 micrometer [of gap lengths], and spacing 0.06micrometer, and coercive force Hc is shown in drawing 9 . The minimal value in each curve in drawing 9 serves as conditions which can attain the minimum magnetic-domain width of face recordable by the Bs, i.e., the highest recording density. It is equivalent to the greatest Hc which needs the minimal value of each curve of drawing 9 to attain each highest recording density in Bs. That is, it is 2200 at Bs=0.8T. It is 2800 at Oe and Bs=1.0T. It is 3500 at Oe and Bs=1.2T. It is 4500 at Oe and Bs=1.6T. It is Oe. As for Hc of this result to a magnetic-recording medium, it is more desirable that Bs of a head is 1/4 or less further 1/2 or less in a system of CGS units.

(4) The lubricant used by the conventional magnetic-recording medium may be applied to the magnetic-recording medium by mechanical structure this invention on the front face of a magnetic thin film for protection of a medium. In this case, in the magnetic thin film in this invention, there is an advantage whose adhesion lubricant is embedded in the opening which exists in a nonmagnetic base material part or the interface part of a nonmagnetic base material and magnetic metal particles, and improves. Moreover, in order to embed lubricant positively in an opening, an opening may be alternatively formed in the interface part of magnetic metal particles, or a nonmagnetic base material and magnetic metal particles by grinding after medium production. Since this opening demonstrates sufficient adhesion, it is desirable that they are the radius of 1nm or more and a depth of 2nm or more.

[0056] Furthermore, in order to realize high density record using the magnetic-recording medium of this invention, the various physical properties which the magnetic metal particles itself should fulfill are examined.

(5) If the magnetic substance becomes very small at the general volume of magnetic metal particles, it is known that it becomes impossible to arrange magnetization in the fixed direction by thermal fluctuation. Time amount change of the magnetization I by the thermal fluctuation of the magnetic substance of the volume v with anisotropy energy Ku is $I(t) = I_0 \exp(-t/\tau)$.

It is come out and expressed. Here, t is time amount, I_0 is the value of the first magnetization, and τ is $\tau = \tau_0$ and $\exp(v \cdot Ku/kT)$.

It is come out and expressed. Here, it is τ_0 . About 10^{-9} k is a Boltzmann's constant, and T is absolute temperature. Conditions for τ to fill practical record holding-time ten years in a room temperature ($T=300K$) are set to $v \cdot Ku < 1.7 \times 10^{-19} J$ from this formula. SmCo is taken for an example and it is $9.5 \times 10^6 J/m^3$ to Ku. It will be set to $v = 1.8 \times 10^{-26} m^3$ if it substitutes. Therefore, if it is the volume beyond this value, there is no disappearance of the magnetization by thermal fluctuation, and it can use preferably as a magnetic-recording medium.

(6) On the size magnetic thin film of a magnetic cluster, a magnetic domain is formed of the field from the magnetic head, and this becomes one unit of informational record. At this time, if larger than the magnetic domain in which the minimum magnetic-domain size of that magnetic thin film should be formed, the S/N ratio of a signal deteriorates, and when the worst, it will become unreproducible. The minimum magnetic-domain size can estimate a magnetic-recording medium with the magnetic cluster size when carrying out alternating current demagnetization. 1 GB/in² It is known that the line lay length of the record magnetic domain which attains recording density is 150nm (3078 28 Murdock:IEEE Trans.Magn., Vol. p. 1992). Therefore, if average magnitude of a magnetic cluster size is made smaller than this value, it will be 1 GB/in². The above high density record is attained. However, since a noise level will become large on practical use level if it is not extent with which some magnetic clusters go into the shorter side of a magnetic domain, as for the magnitude of this magnetic cluster, it is desirable that they are 100nm or less and 50 more nm or less. In order to realize playback of a high S/N ratio, it is more desirable that it is 30nm or less.

(7) The particle size of the particle-size magnetism metal particles of magnetic metal particles being comparable as the size of the magnetic cluster when carrying out alternating current demagnetization of the magnetic-recording medium or the configuration of a magnetic domain formed in a magnetic-recording medium when it is more than it will not be able to reflect the field from a head, but will cause a noise at the time of playback. In this case, if it is 1/10 or less [of the average size of a magnetic cluster when the mean particle diameter in the film surface of magnetic metal particles carries out alternating current demagnetization], the noise at the time of playback can be reduced. What is necessary is here, to observe the front face of a magnetic thin film under a microscope, to measure the pitch diameter and just to average about two or more magnetic metal particles, in order to compute the mean particle diameter in the film surface of magnetic metal particles. In addition, the configuration of the magnetic metal particles observed from the magnetic-thin-film front face averages with the number of the magnetic metal particles which crossed the long sum total die length with which 1 or the straight line beyond it is drawn to the microphotography on the front face of the film when cylindrical, and this straight line crosses magnetic metal particles, and computes the mean particle diameter in the film surface of magnetic metal particles. Moreover, when the configuration of the magnetic metal particles observed from the magnetic-thin-film front face is an ellipsoid, it is averaging the die length of the major axis and a minor axis, and the

mean particle diameter in the film surface of magnetic metal particles may be computed.

[0057] In the magnetic thin film in this invention, since it is separated from spacing of magnetic metal particles to extent which an exchange interaction does not commit, magnetic metal particles serve as a smallest unit of flux reversal. Therefore, the effectiveness of reducing a noise by the relation between the particle size of the above magnetic metal particles and a magnetic cluster is acquired. Even if it is going to apply this relation as relation between crystal grain and a magnetic cluster in the magnetic-recording medium of the usual metal thin film mold, since one crystal grain does not become, the smallest unit of flux reversal has it. [meaningless]

(8) In order to divide the magnetic interaction between magnetic metal particles and for the magnetic recording of high density to enable it to carry out as spacing between magnetic metal particles carried out the standard deviation above-mentioned, it is said that it is required for the distance between magnetic metal particles to be about 1nm or more.

Moreover, since the uniform coercive force covering the whole magnetic thin film will not be acquired, but a record magnetic-domain configuration will be confused and a noise will increase if dispersion in this distance is large, it is not desirable. In order to prevent this, it is desirable that the standard deviation of spacing of magnetic metal particles is 1nm or less. In order to realize high density record more, it is more desirable that this standard deviation is 0.5nm or less.

[0058]

[Embodiment of the Invention] Hereafter, the gestalt of operation of this invention is concretely explained with reference to a drawing.

(1st operation gestalt) As a cross section showed to drawing 1 using the sputtering method as follows, the magnetic thin film which consists of magnetic metal particles 1 and a nonmagnetic base material 2 was formed on the glass substrate 11. That is, using CoPt and a Si-O target, coincidence sputtering of 2 yuan was performed in 1Pa Ar ambient atmosphere, and the magnetic thin film of 50nm thickness was formed. This magnetic thin film consisted of nonmagnetic base materials which consist of magnetic metal particles which consist of CoPt, and Si-O. The presentation of a nonmagnetic base material is SiO₂. Near and this ingredient have the Vickers hardness of 2GPa(s) in the state of bulk. Moreover, when this magnetic thin film was dipped into the aqua regia and only CoPt was dissolved alternatively, only the part of a nonmagnetic base material maintained the configuration of the original magnetic thin film, and remained, and it was checked that a nonmagnetic base material continues and exists in the direction of thickness and film surface inboard of a magnetic thin film.

[0059] When TEM observation of the above-mentioned magnetic thin film was performed, an image which is looked at by drawing 5 was observed. Moreover, in the center section of CoPt magnetism metal particles, the content of Si and O which are the configuration element of a nonmagnetic base material was below pentatomic %. Moreover, in the specific region of a Si-O nonmagnetic base material, the content of Co which is the magnetic element which constitutes magnetic metal particles was below pentatomic %. It turned out that the interface field of CoPt and Si-O is a Co-O phase as a result of a detailed component analysis. This has the operation which strengthens association with CoPt magnetism metal particles and a Si-O nonmagnetic base material, and when the toughness of the whole magnetic thin film improved, its endurance as a magnetic-recording medium improved.

[0060] When the magnetic properties of this magnetic thin film were measured, it had the perpendicular magnetic anisotropy, and coercive force Hc was about 160 kA/m (2000 Oe), and saturation magnetization Is was about 0.5 Wb/m² (400G). When TEM observation of the magnetic thin film was carried out and the rate of volume filling of CoPt was computed, it was about 0.65 uniformly over the whole thin film. the average volume of magnetic metal particles -- 4x10⁻²⁵m³ it was . 1/10 or less [furthermore, / with a pitch diameter / of the magnetic cluster when the mean particle diameter in the film surface of the magnetic metal particles measured from the magnetic-thin-film front face being 3-4nm, and carrying out alternating current demagnetization of this sample / of about 50nm] -- it is -- and magnetic metal particles -- the configuration of a ** length spheroid -- it is -- (die length of major axis)/(the die length of a minor axis) -- 2-5, and magnetic shape anisotropy -- 2.1 - 3.2x10⁵ J/m³ it was . moreover, the place which estimated the crystal magnetic anisotropy of CoPt magnetism metal particles by magnetic torque measurement -- 2x10⁶ J/m³ it was . Moreover, when the probe was contacted on the surface of the magnetic thin film and electrical resistivity was measured, they were about 10 ohm-cm.

[0061] In order to raise the property of the above-mentioned magnetic thin film, the alloying element was added to magnetic metal particles and a nonmagnetic base material. First, B was added to the magnetic metal particles in a magnetic thin film by performing sputtering using the CoPt target which added B. By this, coercive force improved to 220 kA/m. When TEM (transmission electron microscope) performed the component analysis at this time, an average of B concentration in a nonmagnetic base material was 1/50 or less [of an average of B concentration in the magnetic metal-particles section]. Ta was added to the nonmagnetic base material in a magnetic thin film by on the other hand

performing sputtering using the Si-O target which added Ta. By this, the conductivity of a magnetic thin film increased, it became about ten to 2 ohm-cm, and the damage probability of the component by the current leak from MR head decreased. When TEM performed the component analysis at this time, the average Ta concentration of the magnetic metal-particles section was 1/10 or less [of Ta concentration of the average in a nonmagnetic base material]. Moreover, B was added to both magnetic metal particles and a nonmagnetic base material by performing sputtering using the CoPt target which added B, and the Si-O target which added B. Coercive force became 220 kA/m by addition of B to magnetic metal particles. Moreover, the distortion of the whole magnetic thin film decreased by B addition to a nonmagnetic base material, and the endurance as a magnetic-recording medium improved.

[0062] When the above-mentioned magnetic thin film was formed in the 2.5 inches disk-like glass substrate, record / playback evaluation was actually performed and the noise level was measured using the spectrum analyzer, in the case of which [above], the noise level after record of a signal was the same as DC elimination noise level. Moreover, when the CSS (Contact Start Stop) trial usually used for the sliding characterization of a magnetic-recording head / medium was performed, 500,000 times or more of endurance was acquired in the condition without a protective coat.

(2nd operation gestalt) The magnetic thin film was formed on the glass substrate like drawing 1 using the sputtering method as follows. That is, using Co, Fe, and aluminum target, coincidence sputtering of 3 yuan was performed in Ar ambient atmosphere of 10% of oxygen tension, and the magnetic thin film of 200nm thickness was formed. This magnetic thin film is the magnetic metal particles and aluminum 2O₃ which consist of FeCo. It consisted of nonmagnetic base materials which have a near presentation. The ingredient of this nonmagnetic base material has the Vickers hardness of 12GPa(s) in the state of bulk. Moreover, when this magnetic thin film was dipped into the aqua regia and only FeCo was dissolved alternatively, only the part of a nonmagnetic base material maintained the configuration of the original magnetic thin film, and remained, and it was checked that a nonmagnetic base material continues and exists in the direction of thickness and film surface inboard of a magnetic thin film.

[0063] When TEM observation of the above-mentioned magnetic thin film was performed, an image which is looked at by drawing 5 was observed. Moreover, in the center section of FeCo magnetism metal particles, the content of aluminum and O which are the configuration element of a nonmagnetic base material was below pentatomic %. Moreover, in the specific region of an aluminum-O nonmagnetic base material, the content of Co and Fe which are the magnetic element which constitutes magnetic metal particles was below pentatomic %. When the component analysis of the interface field of FeCo and aluminum-O was performed, it turned out that a very thin FeCo-O phase exists. This has the operation which strengthens association with FeCo magnetism metal particles and an aluminum-O nonmagnetic base material, and when the toughness of the whole magnetic thin film improved, its endurance as a magnetic-recording medium improved.

[0064] the place which measured the magnetic properties of this magnetic thin film -- the magnetic anisotropy within a field -- having -- coercive force Hc -- about 160 kA/m and saturation magnetization Is -- about 1 Wb/m² it was . When TEM observation of the magnetic thin film was carried out and the rate of volume filling of FeCo was computed, it was about 0.65 uniformly over the whole thin film. the average volume of magnetic metal particles -- 4x10⁻²⁵m³ it was . 1/10 or less [furthermore, / with a pitch diameter / of the magnetic cluster when the mean particle diameter in the film surface of the magnetic metal particles measured from the magnetic-thin-film front face being 3-4nm, and carrying out alternating current demagnetization of this sample / of about 50nm] -- it is -- and magnetic metal particles -- the configuration of a ** length spheroid -- it is -- (die length of major axis)/(the die length of a minor axis) -- 2-5, and magnetic shape anisotropy -- 5.4 - 8.2x10⁵ J/m³ it was . moreover, the place which estimated the crystal magnetic anisotropy of FeCo magnetism metal particles by magnetic torque measurement -- 106 J/m³ it was . When the probe was contacted on the surface of the magnetic thin film and electrical resistivity was measured, they were about 10 ohm-cm.

[0065] Next, in addition to three sorts of above-mentioned targets, coincidence sputtering of 4 yuan was further performed in Ar ambient atmosphere of 10% of oxygen tension using Cr target, and the magnetic thin film of 20nm thickness was formed. This magnetic thin film is the magnetic metal particles and aluminum 2O₃ which consist of FeCoCr. It consisted of aluminum-O nonmagnetic base materials which have a near presentation. In this case, the coercive force Hc of a magnetic thin film became about 180 kA/m. When the component analysis of the interface field of FeCo and aluminum-O was performed, it turned out that a very thin FeCo-O phase and Cr phase exist. This has the operation which strengthens association with FeCo magnetism metal particles and an aluminum-O nonmagnetic base material, and when the toughness of the whole magnetic thin film improved, its endurance as a magnetic-recording medium improved.

[0066] Moreover, when the magnetic thin film of 4 yuan was formed by coincidence sputtering like the above except having performed bias sputtering, the coercive force of the obtained magnetic thin film became 220 kA/m.

[0067] Furthermore, the magnetic thin film of 4 yuan was formed by coincidence sputtering like the above, impressing the field of an average of 40 kA/m perpendicularly to a substrate with a permanent magnet. The major axis of the magnetic metal particles in the obtained magnetic thin film has turned to the direction almost perpendicular to a film surface, and perpendicular magnetic anisotropy films were obtained.

[0068] In addition, also when nitrogen and organic gas are used as reactant gas, such as Ta, W, Hf, V, In, Si, and B, as an alloying element of magnetic metals, such as Zr, Ti, and B, as ingredients which form a nonmagnetic base material, such as Pt, Sm, and nickel, as an ingredient which constitutes magnetic metal particles, the same result as the above is obtained.

[0069] When the above-mentioned magnetic thin film was formed in the 2.5 inches disk-like glass substrate, record / playback evaluation was actually performed and the noise level was measured using the spectrum analyzer, in the case of which [above], the noise level after record of a signal was the same as DC elimination noise level. Moreover, when the CSS trial usually used for the sliding characterization of a magnetic-recording head / medium was performed, 500,000 times or more of endurance was acquired in the condition without a protective coat.

(3rd operation gestalt) As shown in drawing 2 using the sputtering method as follows, the magnetic thin film which consists of magnetic metal particles 1 and a nonmagnetic base material 2 was formed on the soft magnetism substrate layer 12 formed on the glass substrate 11. That is, first, sputtering was performed in Ar ambient atmosphere using the MnBi target, and the soft magnetism substrate layer 12 was formed on the glass substrate 11. Subsequently, using the multicomponent target arranged in the shape of a mosaic, MnBi and C performed sputtering in Ar ambient atmosphere, and formed the magnetic thin film of 50nm thickness on the soft magnetism substrate layer 12. Then, the deposited magnetic thin film was annealed at 400 degrees C for 2 hours. This magnetic thin film consisted of nonmagnetic base materials which consist of magnetic metal particles which consist of MnBi, and C. Moreover, the structure analysis showed that C which constitutes a nonmagnetic base material was diamond-like carbon. Moreover, when this magnetic thin film was dipped into the aqua regia and only MnBi was dissolved alternatively, only the part of a nonmagnetic base material maintained the configuration of the original magnetic thin film, and remained, and it was checked that a nonmagnetic base material continues and exists in the direction of thickness and film surface inboard of a magnetic thin film.

[0070] When TEM observation of the above-mentioned magnetic thin film was performed, an image which is looked at by drawing 3 was observed. Moreover, in the center section of MnBi magnetism metal particles, the content of C which is the configuration element of a nonmagnetic base material was below 10 atom %. Moreover, in the specific region of C nonmagnetic base material, the content of Mn and Bi which are the magnetic element which constitutes magnetic metal particles was below 10 atom %.

[0071] the place which measured the magnetic properties of this magnetic thin film -- a perpendicular magnetic anisotropy -- having -- coercive force H_c -- about 160 kA/m and saturation magnetization I_s -- about 1 Wb/m² it was . When TEM observation of the magnetic thin film was carried out and the rate of volume filling of MnBi was computed, it was about 0.65 uniformly over the whole thin film. the average volume of magnetic metal particles -- $4 \times 10^{-25} m^3$ it was . 1/10 or less [furthermore, / with a pitch diameter / of the magnetic cluster when the mean particle diameter in the film surface of the magnetic metal particles measured from the magnetic-thin-film front face being 3-4nm, and carrying out alternating current demagnetization of this sample / of about 50nm] -- it is -- and magnetic metal particles -- the configuration of a ** length spheroid -- it is -- (die length of major axis)/(the die length of a minor axis) -- 2-5, and magnetic shape anisotropy -- 1.7 - 2.6x10⁵ J/m³ it was . moreover, the place which estimated the crystal magnetic anisotropy of MnBi MAG metal particles by magnetic torque measurement -- 8×10^5 J/m³ it was . Moreover, it was 8nm when the standard deviation of spacing of the magnetic metal particles on the front face of a magnetic thin film was measured.

[0072] When the above-mentioned magnetic thin film was formed in the 2.5 inches disk-like glass substrate, record / playback evaluation was actually performed and the noise level was measured using the spectrum analyzer, in the case of which [above], the noise level after record of a signal was the same as DC elimination noise level. Moreover, when the CSS trial usually used for the sliding characterization of a magnetic-recording head / medium was performed, 500,000 times or more of endurance was acquired in the condition without a protective coat.

(4th operation gestalt) As shown in drawing 2 using the sputtering method as follows, the magnetic thin film which consists of magnetic metal particles 1 and a nonmagnetic base material 2 was formed on the nonmagnetic substrate layer 12 formed on the glass substrate 11. First, sputtering was performed in Ar ambient atmosphere using Cr target, and the nonmagnetic substrate layer 12 was formed on the glass substrate 11. Succeedingly, using CoPt, CrTa, and Si target, coincidence bias sputtering of 3 yuan was performed in Ar ambient atmosphere of 10% partial pressure of nitrogen, and the magnetic thin film was formed on the nonmagnetic substrate layer 12. This magnetic thin film consisted of

nonmagnetic base materials which consist of magnetic metal particles which consist of CoPtCrTa, and Si-N. Moreover, when this magnetic thin film was dipped into the aqua regia and only CoPtCrTa was dissolved alternatively, only the part of a nonmagnetic base material maintained the configuration of the original magnetic thin film, and remained, and it was checked that a nonmagnetic base material continues and exists in the direction of thickness and film surface inboard of a magnetic thin film.

[0073] When TEM observation of the above-mentioned magnetic thin film was performed, an image which is looked at by drawing 5 was observed. Moreover, in the center section of CoPtCrTa magnetism metal particles, the content of Si and N which are the configuration element of a nonmagnetic base material was below pentatomic %. Moreover, in the specific region (center section) of a Si-N nonmagnetic base material, the content of Co and Pt which are the magnetic element which constitutes magnetic metal particles was below 1 atom %. Moreover, when the component analysis of the interface field of CoPtCrTa and Si-N was performed, it turned out that very thin Cr phase exists. This has the operation which strengthens association with CoPtCrTa magnetism metal particles and a Si-N nonmagnetic base material, and when the toughness of the whole magnetic thin film improved, its endurance as a magnetic-recording medium improved. Moreover, induction of the presentation modulated structure within magnetic metal particles was carried out, and there was an operation which raises magnetic properties, especially coercive force.

[0074] the place which measured the magnetic properties of this magnetic thin film -- the magnetic anisotropy within a field -- having -- coercive force Hc -- about 200 kA/m and saturation magnetization Is -- about 0.8 Wb/m² it was . When TEM observation of the magnetic thin film was carried out and the rate of volume filling of CoPtCrTa was computed, it was about 0.5 uniformly over the whole thin film. the average volume of magnetic metal particles -- 4x10-25m³ it was . 1/10 or less [furthermore, / with a pitch diameter / of the magnetic cluster when the mean particle diameter in the film surface of the magnetic metal particles measured from the magnetic-thin-film front face being 3-4nm, and carrying out alternating current demagnetization of this sample / of about 50nm] -- it is -- and magnetic metal particles -- the configuration of a ** length spheroid -- it is -- (die length of major axis)/(the die length of a minor axis) - - 2-5, and magnetic shape anisotropy -- 3.4 - 5.1x105 J/m³ it was . moreover, the place which estimated the crystal magnetic anisotropy of CoPtCrTa magnetism metal particles by magnetic torque measurement -- 2x106 J/m³ it was .

[0075] When this magnetic-recording medium was attached in drive equipment, the head was contacted by the quiescent state and several electrical resistivity between a head and a spindle was measured, all were about 10 to 2 or more ohm-cm. Moreover, in the record component of this head, when the saturation magnetic flux density Bs of a magnetic pole part set it as 0.4T, record sufficient in coercive force 200 kA/m (2.5k0e) was not completed, the noise increased, in a signal/noise ratio (S/N ratio), it was small and high density record was not completed. On the other hand, when the saturation magnetic flux density Bs of a magnetic pole part set it as 1T, the noise decreased and the S/N ratio increased 8dB.

[0076] When the cross-section structure of this magnetic thin film was observed using TEM, a large number [the radius of 2nm and an about / depth 3nm / opening] were checked on the front face. This magnitude is the diameter of several angstroms, and sufficient magnitude for a lubricant molecule with a die length of several nm to enter.

[0077] When applied lubricant to the magnetic-recording medium which has this magnetic thin film, it was made to run a head in the state of contact and adhesion was investigated, it turned out that endurance improved compared with the case of the magnetic-recording medium which consists of a CoPtCrTa metal thin film. Moreover, since it can delete in the part of the part of magnetic metal particles, and a nonmagnetic base material and directions differ in the case of the burnishing process which is a last process of lubricant spreading, a more bigger opening than many can be formed in a front face using this. Therefore, in the magnetic thin film in the magnetic-recording medium of this invention, it has the advantage which can make lubricant easily, without increasing a process especially for the opening for embedding compared with the metal thin film medium which can be shaved to homogeneity in the direction of thickness.

[0078] Using CoPt, CrTa, Si-O, and Si target, except performing coincidence bias sputtering of 4 yuan in Ar ambient atmosphere of 10% partial pressure of nitrogen, it is the same process and the magnetic thin film which consists of CoPtCrTa magnetism metal particles and a Si-N nonmagnetic base material was formed on the nonmagnetic substrate layer in order to raise the magnetic properties of the above-mentioned magnetic thin film.

[0079] the place which measured the magnetic properties of this magnetic thin film -- the magnetic anisotropy within a field -- having -- coercive force Hc -- about 220 kA/m and saturation magnetization Is -- about 0.9 Wb/m² it was . When TEM performed the component analysis of the detailed field of a magnetic thin film, in the center section of CoPtCrTa magnetism metal particles, the content of O of the content of Si and N which are the configuration element of a nonmagnetic base material was below 10 atom % below 1 atom %. Moreover, in the center section of the Si-N nonmagnetic base material, the content of Co and Pt which are the magnetic element which constitutes magnetic metal particles was below 1 atom %. moreover, the interface field of CoPtCrTa magnetism metal particles and a Si-N

nonmagnetic base material -- a volume phase -- existing -- **** -- this volume phase -- Cr and SiO₂ from -- it turned out that it is constituted. These Cr and SiO₂ There is an operation which strengthens association with CoPtCrTa magnetism metal particles and a Si-N nonmagnetic base material, and when the toughness of the whole magnetic thin film improved, the endurance as a magnetic-recording medium improved. Moreover, there is an operation which raises coercive force by carrying out induction of the presentation modulated structure within magnetic metal particles, and preventing the counter diffusion of a configuration atom.

[0080] In order to investigate the effectiveness of a nonmagnetic Cr substrate layer, the magnetic thin film was formed on the glass substrate as an example of a comparison, without preparing a nonmagnetic substrate layer. although this magnetic thin film has the structure where magnetic metal particles and a nonmagnetic base material were separated -- the crystallinity of magnetic metal particles -- bad -- coercive force -- 80 kA/m and a crystal magnetic anisotropy -- 2x10⁵ J/m³ it was .

[0081] When it reproduced by the MRR head which installed the magnetic-recording medium using the above-mentioned magnetic thin film in the slider of a surfacing mold, the probability of the electrostatic discharge of MR component by the charge up of a medium increased. Then, conductivity was given to the nonmagnetic base material of a medium. First, the magnetic thin film which consists of CoPtCrTa magnetism metal particles and a Ti-N nonmagnetic base material in the same process as the above was formed on the glass substrate except using Ti instead of Si. When this magnetic thin film was dipped into the aqua regia and only CoPtCrTa was dissolved alternatively, only the part of a nonmagnetic base material maintained the configuration of the original magnetic thin film, and remained, and it was checked that a nonmagnetic base material continues and exists in the direction of thickness and film surface inboard of a magnetic thin film. Moreover, the magnetic properties of this magnetic thin film were the same as that of the magnetic thin film shown above almost.

[0082] When this magnetic-recording medium was attached in drive equipment, the head was contacted by the quiescent state and several electrical resistivity between a head and a spindle was measured, all were about 5x10 to 2 or more ohm-cm. The damage probability of MR head decreased by using the magnetic-recording medium which has this magnetic thin film.

[0083] Furthermore, the magnetic thin film which consists of CoPtCrTa magnetism metal particles and an InSnO (ITO) nonmagnetic base material in the same process as the above was formed on the glass substrate except using In-Sn-O instead of Si, and using oxygen instead of nitrogen. When this magnetic thin film was dipped into the aqua regia and only CoPtCrTa was dissolved alternatively, only the part of a nonmagnetic base material maintained the configuration of the original magnetic thin film, and remained, and it was checked that a nonmagnetic base material continues and exists in the direction of thickness and film surface inboard of a magnetic thin film. Moreover, the magnetic properties of this magnetic thin film were the same as that of the magnetic thin film shown above almost.

[0084] When this magnetic-recording medium was attached in drive equipment, the head was contacted by the quiescent state and several electrical resistivity between a head and a spindle was measured, all were about 10 to 3 or more ohm-cm. By using the magnetic-recording medium which has this magnetic thin film, the damage probability of MR head decreased further.

[0085] When the above-mentioned magnetic thin film was formed in the 2.5 inches disk-like glass substrate, record / playback evaluation was actually performed and the noise level was measured using the spectrum analyzer, in the case of which [above], the noise level after record of a signal was the same as DC elimination noise level. Moreover, when the CSS trial usually used for the sliding characterization of a magnetic-recording head / medium was performed, 500,000 times or more of endurance was acquired in the condition without a protective coat.

(5th operation gestalt) In forming the same magnetic thin film as the 1st operation gestalt, the injection power ratio to a CoPt target and a Si-O target was changed by three sorts of approaches, as shown in drawing 10 . The approach of A is an approach of changing an injection power ratio periodically in the shape of a sine wave. The approach of B is an approach to which the ratio of the injection power to CoPt to the injection power to Si-O is made to increase gradually. The approach of C is an approach of decreasing gradually the ratio of the injection power to CoPt to the injection power to Si-O. TEM observation of the cross section of the magnetic thin film obtained by the all directions method was carried out, and change of the filling factor of the magnetic metal particles of the direction of thickness and the property of a magnetic thin film were investigated.

[0086] Exfoliation hardly produced the magnetic thin film obtained by the approach of changing an injection power ratio like A in the friction test which used adhesive tape. On the other hand, in the magnetic thin film obtained by fixing, exfoliation tended to produce an injection power ratio. This result shows that the internal stress of a magnetic thin film is eased by the approach of A. Moreover, when this magnetic thin film was dipped into the aqua regia and only CoPt was dissolved alternatively, only the part of a nonmagnetic base material maintained the configuration of the original

magnetic thin film, and remained, and it was checked that a nonmagnetic base material continues and exists in the direction of thickness and film surface inboard of a magnetic thin film.

[0087] In the magnetic thin film obtained by the approach of changing an injection power ratio like B, the filling factor of CoPt became large as it went to the front-face side of a magnetic thin film. Moreover, with this magnetic thin film, exfoliation did not arise at all in the friction test by adhesive tape.

[0088] In the magnetic thin film obtained by the approach of changing an injection power ratio like C, the filling factor of CoPt became small as it went to the front-face side of a magnetic thin film. When the probe was contacted on the surface of the magnetic thin film and electrical resistivity was measured, it became about 80% of the electrical resistivity of the magnetic thin film obtained by fixing an injection power ratio.

[0089] In addition, when reverse sputtering was performed before forming a magnetic thin film on a glass substrate, it was admitted that the adhesion of a magnetic thin film improved. For example, the rate of exfoliation according to a friction test also in the magnetic thin film obtained by fixing an injection power ratio fell. Moreover, the coercive force of a magnetic thin film increased to 200 kA/m from 160 kA/m. Such effectiveness is demonstrated by the granularity on the front face of a substrate having changed, and having disappeared in the suspension oxygen on the front face of a substrate, when Ar ion is irradiated by the glass substrate in the case of sputter etching processing. In addition, the same effectiveness is acquired by surface treatment methods other than sputter etching processing, for example, a neutron beam exposure and ion plating.

[0090] When the above-mentioned magnetic thin film was formed in the 2.5 inches disk-like glass substrate, record / playback evaluation was actually performed and the noise level was measured using the spectrum analyzer, in the case of which [above], the noise level after record of a signal was the same as DC elimination noise level. Moreover, when the CSS trial usually used for the sliding characterization of a magnetic-recording head / medium was performed, 500,000 times or more of endurance was acquired in the condition without a protective coat.

[0091]

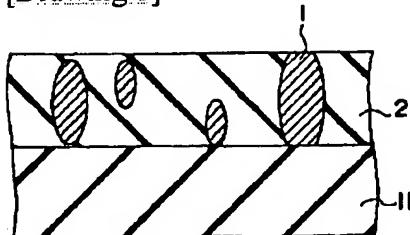
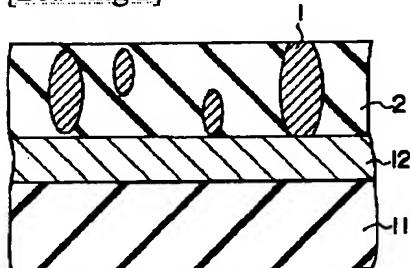
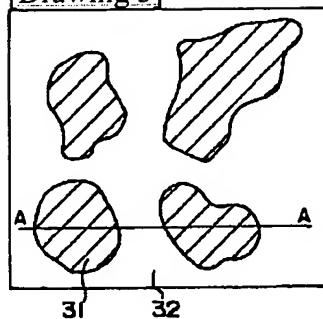
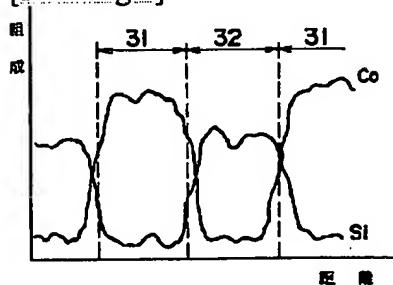
[Effect of the Invention] The magnetic-recording medium of this invention has the magnetic thin film which consists of magnetic metal particles and a nonmagnetic base material, as explained above, the degree of hardness of a nonmagnetic base material is larger than the degree of hardness of magnetic metal particles, magnetic metal particles have magnetic shape anisotropy and a crystal magnetic anisotropy, and since the content of the magnetic metallic element of the center section between the magnetic metal particles in a nonmagnetic base material is below 20 atom %, high density record is possible.

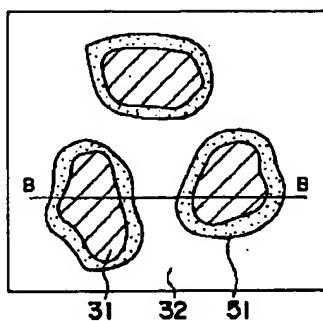
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*** NOTICES ***

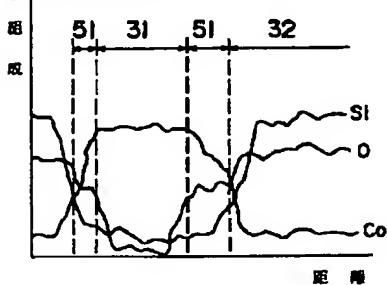
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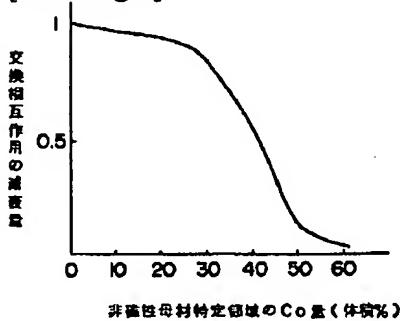
DRAWINGS**[Drawing 1]****[Drawing 2]****[Drawing 3]****[Drawing 4]****[Drawing 5]**



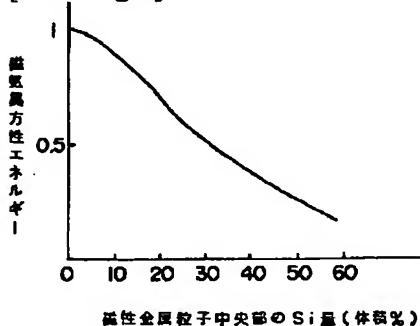
[Drawing 6]



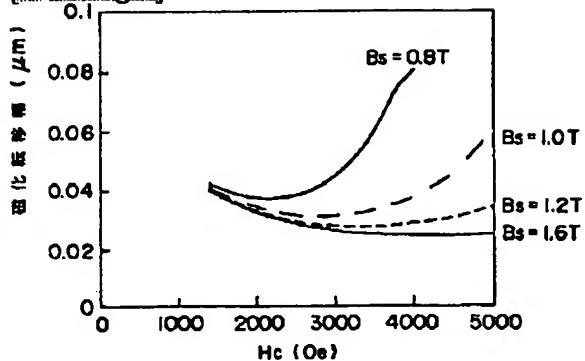
[Drawing 7]



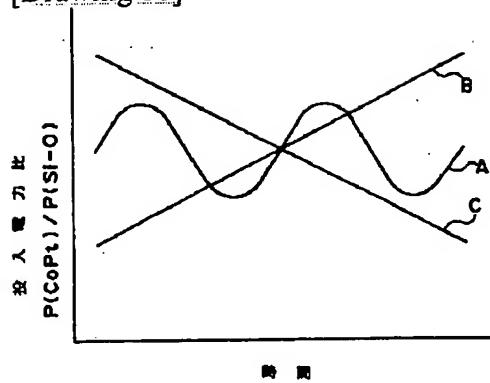
[Drawing 8]



[Drawing 9]



[Drawing 10]



[Translation done.]

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CORRECTION OR AMENDMENT

[Kind of official gazette] Printing of amendment by the convention of 2 of Article 17 of Patent Law

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[Procedure amendment 1]

[Document to be Amended] Specification

[Item(s) to be Amended] Claim

[Method of Amendment] Modification

[Proposed Amendment]

[Claim(s)]

[Claim 1] The magnetic-recording medium which the degree of hardness of said nonmagnetic base material is larger than the degree of hardness of said magnetic metal particles, and said magnetic metal particles have magnetic shape anisotropy and a crystal magnetic anisotropy in the magnetic-recording medium which has the magnetic thin film which consists of magnetic metal particles and a nonmagnetic base material, and is characterized by the content of the magnetic metallic element of the center section between said magnetic metal particles in said nonmagnetic base material being below 20 atom %.

[Claim 2] The magnetic-recording medium according to claim 1 whose content of the configuration element of said nonmagnetic base material in the center section of said magnetic metal particles is below 20 atom %.

[Claim 3] The magnetic-recording medium according to claim 1 by which said magnetic metal particles consist of at least one chosen from Co, Pt, Sm, Fe, nickel, Cr, Mn, Bi, aluminum, and the group that consists of these alloys.

[Claim 4] The magnetic-recording medium according to claim 1 by which said nonmagnetic base material consists of an allotrope of the compound expressed with general formula M-G (at least one chosen from the group which M becomes from Si, aluminum, Zr, Ti, and B, and at least one chosen from the group which G becomes from oxygen, nitrogen, and carbon), or carbon.

[Claim 5] The magnetic-recording medium according to claim 1 whose filling factor to said nonmagnetic base material of said magnetic metal particles is 0.7 or less.

[Claim 6] The magnetic-recording medium according to claim 1 from which the filling factor of said magnetic metal particles is changing along the direction of thickness of said magnetic thin film.

[Claim 7] The magnetic-recording medium according to claim 1 whose mean particle diameter in the film surface of

said magnetic metal particles is 1/10 or less [of the average size of the magnetic cluster when carrying out alternating current demagnetization].

[Claim 8] The magnetic-recording medium according to claim 1 whose electrical resistivity of said magnetic thin film is 10 to 4 or more ohm-cm.

[Claim 9] It is the magnetic recorder and reproducing device whose content of the magnetic metallic element of the center section between said magnetic metal particles [in / it is the magnetic recorder and reproducing device characterized by providing the following, and said magnetic-recording medium has the degree of hardness of said nonmagnetic base material larger than the degree of hardness of said magnetic metal particles, and said trend-of-the-times metal particles have magnetic shape anisotropy and a crystal magnetic anisotropy, and / said nonmagnetic base material] is below 20 atom %. The magnetic-recording medium which has the magnetic thin film which consists of magnetic metal particles and a nonmagnetic base material The magnetic head which reproduces the signal from said magnetic-recording medium using the resistance change by the field

[Claim 10] The magnetic recorder and reproducing device according to claim 9 with which said magnetic-recording medium is used in the condition of contacting said magnetic head.

[Claim 11] Have the magnetic thin film built with two or more magnetic metal particles and nonmagnetic base materials, and the degree of hardness of said nonmagnetic base material is larger than the degree of hardness of two or more of said magnetic metal particles. Said two or more magnetic metal particles have magnetic shape anisotropy and a crystal magnetic anisotropy. The magnetic-recording medium characterized by the content of the magnetic metallic element in 10 - 90% of field of the mean distance measured in the plane section between what said two or more particles between the boundaries of said two or more particles and said nonmagnetic base material adjoin being below 20 atom %.

[Claim 12] Have the magnetic thin film built with two or more magnetic metal particles and nonmagnetic base materials, and the degree of hardness of said nonmagnetic base material is larger than the degree of hardness of two or more of said magnetic metal particles. Said two or more magnetic metal particles have magnetic shape anisotropy and a crystal magnetic anisotropy. The content of the magnetic metallic element in 10 - 90% of field of the mean distance measured in the plane section between what said two or more particles between the boundaries of said two or more particles and said nonmagnetic base material adjoin is below 20 atom %. The mean particle diameter in the field inboard of two or more of said magnetic metal particles is a magnetic-recording medium characterized by being 1/10 or less [of the average size of two or more magnetic clusters when alternating current demagnetization is made].

[Claim 13] The magnetic-recording medium which has the magnetic thin film made from two or more magnetic metal particles held at the nonmagnetic base material and said nonmagnetic base material,

The magnetic head which reproduces a signal from a magnetic-recording medium in the first half using resistance change produced by the field is provided,

Said nonmagnetic base material is following the direction of thickness and field inboard of said magnetic thin film. The degree of hardness of said nonmagnetic base material is larger than the degree of hardness of two or more of said magnetic metal particles. Said two or more magnetic metal particles have magnetic shape anisotropy and a crystal magnetic anisotropy. The magnetic recorder and reproducing device characterized by the content of the magnetic metallic element in 10 - 90% of field of the mean distance measured in the plane section between what said two or more particles between the boundaries of said two or more particles and said nonmagnetic base material adjoin being below 20 atom %.

[Translation done.]

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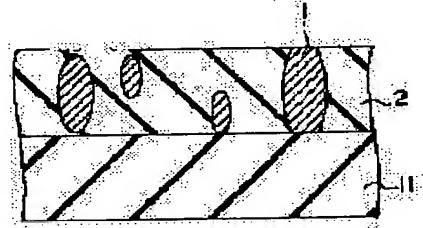
Priority number : 06158842 Priority date : 11.07.1994 Priority country : JP

(54) MAGNETIC RECORDING MEDIUM AND MAGNETIC RECORDING AND REPRODUCING DEVICE

(57)Abstract:

PURPOSE: To obtain a magnetic recording medium capable of high density recording.

CONSTITUTION: This magnetic recording medium has a magnetic thin film consisting of magnetic metal particles 1 and a nonmagnetic matrix 2 whose hardness is higher than that of the particles 1. The particles 1 have shape magnetic anisotropy and crystal magnetic anisotropy and the magnetic metal content of central parts between the particles 1 in the matrix 2 is ≤20at.%.



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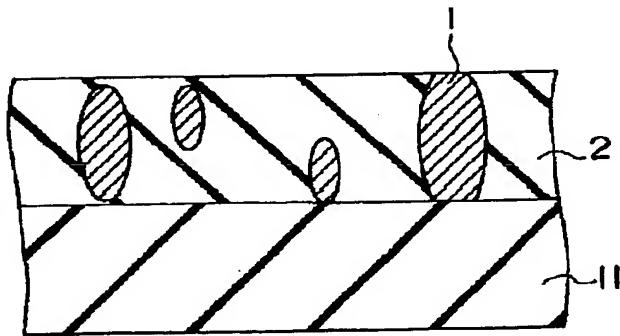
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(54)【発明の名称】磁気記録媒体および磁気記録再生装置

(57)【要約】

【課題】 本発明は、高密度記録が可能な磁気記録媒体を提供することを目的とする。

【解決手段】 磁性金属粒子と非磁性母材とから構成される磁性薄膜を有する磁気記録媒体において、前記非磁性母材の硬度が前記磁性金属粒子の硬度よりも大きく、前記磁性金属粒子が形状磁気異方性および結晶磁気異方性を有しており、前記非磁性母材における前記磁性金属粒子間の中央部の磁性金属元素の含有率が20原子%以下であることを特徴としている。



【特許請求の範囲】

【請求項 1】 磁性金属粒子と非磁性母材とから構成される磁性薄膜を有する磁気記録媒体において、前記非磁性母材の硬度が前記磁性金属粒子の硬度よりも大きく、前記磁性金属粒子が形状磁気異方性および結晶磁気異方性を有しており、前記非磁性母材における前記磁性金属粒子間の中央部の磁性金属元素の含有率が 20 原子%以下であることを特徴とする磁気記録媒体。

【請求項 2】 前記磁性金属粒子の中央部における前記非磁性母材の構成元素の含有率が 20 原子%以下である請求項 1 記載の磁気記録媒体。

【請求項 3】 前記磁性金属粒子が、Co、Pt、Sm、Fe、Ni、Cr、Mn、Bi、Al、およびこれらの合金からなる群より選ばれた少なくとも 1 つからなる請求項 1 記載の磁気記録媒体。

【請求項 4】 前記非磁性母材が、一般式 M-G (M は Si、Al、Zr、Ti および B からなる群より選ばれた少なくとも 1 つ、G は酸素、窒素および炭素からなる群より選ばれた少なくとも 1 つ) で表される化合物、または炭素の同素体からなる請求項 1 記載の磁気記録媒体。

【請求項 5】 前記磁性金属粒子の前記非磁性母材に対する充填率が 0.7 以下である請求項 1 記載の磁気記録媒体。

【請求項 6】 前記磁性金属粒子の充填率が前記磁性薄膜の膜厚方向に沿って変化している請求項 1 記載の磁気記録媒体。

【請求項 7】 前記磁性金属粒子の膜面内の平均粒径が、交流消磁したときの磁気クラスターの平均サイズの 1/10 以下である請求項 1 記載の磁気記録媒体。

【請求項 8】 前記磁性薄膜の電気抵抗率が $10^{-1} \Omega \cdot \text{cm}$ 以上である請求項 1 記載の磁気記録媒体。

【請求項 9】 磁性金属粒子と非磁性母材とから構成される磁性薄膜を有する磁気記録媒体と、磁界による抵抗変化を利用して前記磁気記録媒体からの信号を再生する磁気ヘッドとを具備する磁気記録再生装置であって、前記磁気記録媒体は、前記非磁性母材の硬度が前記磁性金属粒子の硬度よりも大きく、前記磁性金属粒子が形状磁気異方性および結晶磁気異方性を有しており、前記非磁性母材における前記磁性金属粒子間の中央部の磁性金属元素の含有率が 20 原子%以下である磁気記録再生装置。

【請求項 10】 前記磁気記録媒体が前記磁気ヘッドと接触する状態で使用される請求項 9 記載の磁気記録再生装置。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】 本発明は、磁気テープ、磁気ディスク等で用いられる磁気記録媒体に関する。

【0002】

【従来の技術】 近年のコンピュータの高性能化に伴い、特にハードディスク用途においては、磁気記録媒体に対しより高密度の記録・再生能力が要求されるようになつてきた。この要求を満たすために、現在では飽和磁化 I_s の大きい CoPt などの磁性金属の薄膜が記録層に用いられている。しかし、これらの磁性金属薄膜は機械的強度に劣るため、記録・再生ヘッドとの衝突時に破損が生じないように、磁性金属薄膜上に硬質の保護層を設け、その上方に記録・再生ヘッドを非常に小さな間隙を保って浮上させている。なお、保護層としては例えばバルク状態でのピッカース硬度が 2 GPa である SiO₂ 薄膜が用いられている。

【0003】 ところで、磁気記録の原理上、記録密度が高密度になればなるほど、記録・再生ヘッドと記録層との距離 (スペーシング) を小さくする必要がある。しかし、保護層を設けるとスペーシングの低減に対する制限となるため、磁気記録媒体の高密度化にとって大きな障害となっている。そこで、非常に薄い保護層を設け、かつヘッドの浮上量を小さくする努力がなされているが、このような保護層の保護性能が低い場合には、かえってヘッドとの接触による磁性金属薄膜の破損の確率は増加してしまう。最近では炭素薄膜などを用いてより薄くかつ保護性能の高い保護層が開発されつつあるが、いずれにしても保護層を設ける限り高密度化に対しての本質的な解決策とはならない。

【0004】 そこで、硬質の酸化物磁性体を用いて磁性薄膜自体の硬度を増加させることが考えられるが、現在知られている酸化物磁性体の磁化の値は小さいため、保護層をなくしたとしても高密度記録には適さない。

【0005】 この他にも、高密度記録を実現するためには、磁性薄膜中において結晶粒間の磁気的相互作用を十分に分断する必要がある。また、一般に基板上に磁性薄膜を形成する場合、磁性薄膜内部に応力が生じて磁性薄膜の密着性や磁気特性などに影響を及ぼすことが知られているため、応力を緩和する必要がある。

【0006】 さらに近年、高感度の磁気ヘッドとして磁気抵抗 (MR) 素子を用いたものが開発されているが、MR ヘッドと磁性薄膜とが接触した際に電気的な導通があると、MR 素子に大電流が流れヘッドが損傷する恐れがある。一方、磁性薄膜が絶縁体である場合は、磁性薄膜上に空気との摩擦等により発生する電荷が蓄積され、そこから素子への放電が起こり、これによりヘッドが損傷する恐れがある。このような現象を避けるためには、磁性薄膜の電気抵抗率が磁気記録装置の構成や材料等に適合した値に設定することが好ましい。しかしながら、これらをすべて満足する高密度記録に適した磁気記録媒体は得られていないのが現状である。

【0007】

【発明が解決しようとする課題】 本発明は上記問題点を解決するためになされたものであり、高密度記録が可能

な磁気記録媒体を提供することを目的とする。

【0008】

【課題を解決するための手段】本発明は、磁性金属粒子と非磁性母材とから構成される磁性薄膜を有する磁気記録媒体において、前記非磁性母材の硬度が前記磁性金属粒子の硬度よりも大きく、前記磁性金属粒子が形状磁気異方性および結晶磁気異方性を有しており、前記非磁性母材における前記磁性金属粒子間の中央部の磁性金属元素の含有率が20原子%以下であることを特徴とする磁気記録媒体を提供する。

【0009】本発明の磁気記録媒体において、磁性金属粒子は磁気記録システムに応じた情報にしたがって所定の方向に磁化され、長手記録、斜め記録または垂直記録が可能である。また、本発明の磁気記録媒体は、記録・再生装置(ヘッド)が磁気記録媒体に接触する方式、ヘッドが磁気記録媒体から浮上する方式のいずれにも適用することができる。

【0010】本発明の磁気記録媒体において、磁性金属粒子は形状磁気異方性および結晶磁気異方性を有するようとする。あるいは、磁性金属粒子は形状磁気異方性エネルギーが 10^4 J/m²以上、好ましくは 5×10^4 J/m²以上であり、結晶磁気異方性エネルギーが 5×10^4 J/m²以上、好ましくは 10^4 J/m²以上であるようにする。

【0011】ここで、形状磁気異方性と結晶磁気異方性について簡単に説明する。磁気異方性とは、物体の方向によって磁気的特性が異なる性質のことであり、その異なる特性の原因が磁性体の形状によるものが形状磁気異方性、結晶構造によるものが結晶磁気異方性である。例えば、針状の磁性体は長軸の方向に磁化され易いので、形状磁気異方性がある。また、Coは結晶構造上のある特定の方向(C軸)が磁化され易いので、結晶磁気異方性がある。また、磁化され易い方向と困難な方向に磁化を向けるのに必要なエネルギーの差が、磁気異方性エネルギーであり、このエネルギーが大きいほど、ある方向に磁化を安定して向けることができる。また、磁気異方性エネルギーが大きいと、記録した情報を安定して保持することができ、また、信号出力を大きくすることができる等の磁気記録媒体にとって好ましい磁気特性が得られる。

【0012】本発明の磁気記録媒体においては、例えば、磁性金属粒子に膜厚方向に細長い形状を有するものを用いて、形状磁気異方性を膜厚方向に付与することによって、垂直磁化膜とすることができる。また、磁性金属粒子にCo基合金を用いて、膜厚方向へ結晶のC軸が向くように成長させることによって、同様に垂直磁化膜とすることができます。磁性金属粒子が形状磁気異方性と結晶磁気異方性の両方を有することによって、より大きな垂直磁気異方性を磁性薄膜に付与することができ、また、垂直・斜め・長手記録用のいずれの磁気記録媒体に

も適用することができる。例えば、Co基合金からなる磁性金属粒子が膜厚方向に細長の形状を有し、かつ結晶のC軸が膜厚方向に沿って成長している場合は、2つの磁気異方性の相乗効果によってより大きな磁気異方性を得ることができる。この場合、保磁力を大きくすることができ、記録磁区の小さな、より高密度の記録ができるようになる。

【0013】長手記録用の媒体の場合は、ある程度の垂直磁気異方性を有する方が高密度記録に適していると言われており、これは、例えば、膜面内方向にC軸が配向している磁性金属粒子が膜厚方向に細長い形状を有することにより実現できる。なお、形状磁気異方性と結晶磁気異方性とはその起源が異なるので、媒体作製プロセスや材料選択等の面で独立に制御し易い。したがって、この2つの磁気異方性を具備することは、高密度の磁気記録媒体にとって好ましいと言える。なお、磁気異方性の大きさや向きは、磁気記録媒体を構成する材料、作製装置、ドライブに要求される仕様等により決定される。

【0014】本発明の磁気記録媒体は、膜厚方向および膜面内方向に連続して存在する非磁性母材並びに非磁性母材内に保持された磁性金属粒子からなる磁性薄膜から構成されている。非磁性母材が磁性薄膜の膜厚方向および膜面内方向に連続して存在するということは、非磁性母材がネットワーク状の構造を持つことを意味する。本発明における非磁性母材は、磁性薄膜全体の機械的強度を向上させ、電気抵抗率を高め、かつ磁性金属粒子間の磁気的相互作用を分断する役割を担っている。

【0015】磁性金属粒子としては、飽和磁化Isが大きく、かつ磁気異方性が大きいものが望ましい。このようなものとして、例えばCo、Pt、Sm、Fe、Ni、Cr、Mn、Bi、Al、またはこれらの合金を用いることができる。特に、大きな結晶磁気異方性を有するCoPt、SmCo、CoCr等のCo基合金や、大きい異方性エネルギーを有するMnBi、MnAl等のMn合金を用いることが好ましい。また、これらの金属または合金に、磁気特性を制御する目的で、Feおよび/またはNiを添加してもよい。さらに、これらの金属または合金に、磁気特性を向上させるために、例えばCr、Nb、V、Ta、Ti、W、Hf、In、Si、B等を添加してもよい。

【0016】磁性金属粒子の形状は、球状であっても良いが、形状磁気異方性を向上させるために円柱状、回転楕円体形状等でも良い。磁性金属粒子は、記録される情報をしたがって所望の方向(例えば、媒体表面の面内、媒体表面に垂直な方向、またはその中間の方向)に磁化され、これにより情報が記録される。磁性金属粒子を、その長軸方向が磁気記録媒体表面の面内方向に傾くように配置すると面内に磁化されやすく、磁気記録媒体表面に対して垂直な方向に傾くように配置すると次第に垂直方向に磁化され易くなる。

【 0 0 1 7 】 磁気記録媒体に磁気ヘッドが接触したときの損傷を防ぐという目的を達成するために磁気記録媒体が満たすべき物理特性を正確に決定することは一般には困難であるが、1つの基準として硬度を採用することができる。原理的には、硬度が大きいほど磁気ヘッドとの接触による磁気記録媒体の損傷が小さくなると考えられる。

【 0 0 1 8 】 このような観点から、非磁性母材としてはバルク状態で高い硬度で高い抵抗率を有するものが用いられる。一般的に、バルクで硬い材料は薄膜化しても充分な硬度を保つ。このような非磁性母材の材料として、例えば一般式 M-G で表される化合物が挙げられる。ここで、M は Si、Al、Zr、Ti、In、Sn および B からなる群より選択される少なくとも 1 種であり、G は酸素、窒素および炭素からなる群より選択される少なくとも 1 種である。具体的には、Si-O、Al-O、Zr-O、Ti-O、Si-N、Al-N、Zr-N、Ti-N、B-N、Si-C、Ti-C、B-C、Si-Al-ON、Si-ON、Al-Ti-OC、In-Sn-O 等が好ましい。また、非磁性母材の材料としては、潤滑性に優れバルク状態で高硬度である炭素の同素体、例えばダイヤモンド、アモルファスカーボン、ダイヤモンドライカーボン等を用いることもできる。これらの非磁性母材を構成する材料のバルクにおける硬度は、バルクの Si₃O₄ が有するピッカース硬度 2 GPa と同程度またはそれ以上であることが好ましい。さらに、非磁性母材の材料として、電気絶縁体または半導体からなる材料を用いることにより、磁気記録媒体全体の電気抵抗率を金属薄膜媒体に比べて大幅に高くすることが可能である。

【 0 0 1 9 】 また、非磁性母材の硬度や耐摩耗性を向上させるために、上記材料に非磁性の元素を添加してもよい。この場合、添加元素が非磁性母材中に固溶していてもよく、相分離した状態で添加されていてもよい。また、添加元素が微粒子の状態で非磁性母材中に存在していてもよい。添加元素が存在する状態は、磁性金属粒子が分散される状態における磁性薄膜の機械的特性や磁気的特性により適宜選択する。

【 0 0 2 0 】 本発明における磁性薄膜は、磁性金属粒子や非磁性母材の特性向上のために上述したような添加元素を加える場合に、磁性金属粒子と非磁性母材と同じ元素が添加されていてもよい。また、後述するように、原子レベルで磁性金属粒子と非磁性母材とが完全に分離された状態の複合膜を形成することは事実上不可能があるので、磁性金属粒子に対する添加元素が非磁性母材中に存在してもよい。この場合、添加元素の効果をより効率的に発揮させるために、非磁性母材中の添加元素は磁性金属粒子内に比べて 1/10 以下、より好ましくは 1/100 以下の割合であればよい。この関係は、非磁性母材と磁性金属粒子とを入れ換えてても成立つ。

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【 0 0 2 1 】 磁性金属粒子と非磁性母材とからなる磁性薄膜を支持する基板としては、金属、ガラス、セラミック等を用いることができる。なお、基板と磁性薄膜との間に、磁性体または非磁性体からなる下地層を設けてよい。特に、金属基板を用いる場合には、磁気ヘッドと磁気記録媒体との間の短絡を防止するために、電気絶縁性を有する下地層を用いることが望ましい。また、磁気記録媒体の表面には、必要に応じて極薄い (10 オンストローム以下) 保護膜を設けてよい。さらに、磁性金属粒子同士は、磁気的交換力が及ばない程度の距離 (1 nm 以上) をおいて非磁性母材に保持されていることが望ましい。これは、電気抵抗を高めるだけでなく、磁気記録媒体の保磁力を向上させ、磁気記録媒体のノイズを低減させるためである。

【 0 0 2 2 】 磁性体からなる下地層は、磁性薄膜に効率的な記録／再生を行なうために、磁性薄膜中の磁区や記録／再生ヘッドと交換相互作用・静磁気相互作用により磁気的に結合されている。磁区と交換結合するように下地層を配置する場合、磁化反転しやすい磁性体からなる下地層を用いて磁区を安定化する方法、あるいは磁化の大きな磁性体からなる下地層を用いて再生出力を増加させる方法等が挙げられる。

【 0 0 2 3 】 非磁性体からなる下地層は、磁性金属粒子や非磁性母材の結晶構造を制御する目的、あるいは基板からの不純物の混入を防ぐ目的で配置される。例えば、磁性金属粒子の所望の結晶構造の格子間隔に近い格子間隔を持つ材料からなる下地層を用いることにより、磁性金属粒子の結晶の格子間隔を制御することが可能である。また、例えば、ある表面エネルギーを有するアモルファス下地層を用いることにより、磁性金属粒子あるいは非磁性母材の結晶性あるいはアモルファス性を制御してもよい。また、基板からの不純物の混入を防止する場合には、格子間隔の小さい薄膜あるいは緻密な薄膜を下地層として用いればよい。上記の磁性体からなる下地層や非磁性体からなる下地層は、他方の持つ機能を有していてよい。すなわち、磁性体からなる下地層が磁性金属粒子の結晶性を制御する特性を有していてよい。この場合には、記録／再生特性上の効果と結晶性における効果とが相乗されるのでより好ましい。また、上記下地層は、イオンプレーティング、雰囲気ガス中でのドーピング、中性子線照射等により基板の表面を改質することにより形成してもよい。これらの方法によれば、薄膜形成工程を介さないので媒体作製上好ましい。

【 0 0 2 4 】 本発明の磁気記録媒体においては、磁性金属粒子と非磁性母材との間に、磁性金属粒子と非磁性母材とを効率よく結合させ、あるいは磁性金属粒子および非磁性母材の構成元素の相互拡散を防止するための界面層が存在していてよい。この界面層には、磁性金属粒子あるいは非磁性母材の少なくとも一方を構成する元素が主成分として存在してもよく、磁性金属粒子および非

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磁性母材を構成する元素がほとんど存在していないともよい。前者の場合、磁性金属粒子と非磁性母材とを機械的に強固に結合させるという点で好ましく、後者は磁性金属粒子と非磁性母材とを磁気的に完全に分離するという点で好ましい。

【0025】本発明における磁性薄膜は、磁性金属材料および非磁性材料を真空中において物理的蒸着法や化学的蒸着法により基板上に堆積させることにより形成する。物理的蒸着法としては、次に示す方法が挙げられる。(a) 磁性金属材料のターゲットおよび非磁性材料のターゲットを用いて同時スパッタリング。(b) 複数の金属材料のターゲットを用い、酸素、窒素または炭素を含む不活性ガス雰囲気中における同時スパッタリング。

【0026】この場合、一部の金属と酸素、窒素または炭素との化合物からなる非磁性母材が形成される。なお、(a) および(b) の場合において、磁性金属粒子と非磁性母材の材料は、それぞれ別々のターゲットに配置されていてもよく、両材料を同じターゲットに配置した複合ターゲットでもよい。前者の場合は、磁気的特性や機械的特性の経時変化に対して対応し易いという利点があり、後者の場合は、大量生産に適しているという利点がある。

【0027】すなわち、これらの薄膜形成方法では、一般に結晶が柱状に成長することが知られている。したがって、投入電力、スパッタリング圧力、反応性ガス種、成膜速度、バイアス電力、添加物の種類等のプロセスパラメータを選択することにより、磁性金属粒子および非磁性母材を共に柱状に成長させることができる。また、スパッタリング法による薄膜形成の場合、一般に磁性金属は柱状に成長し易く、硬質誘電体薄膜はアモルファス化し易い。このことから、スパッタリング法で磁性金属と硬質誘電体材料を同時に成長させることにより、アモルファス化した硬質誘電体からなる非磁性母材中に形状磁気異方性の大きな柱状の磁性金属粒子が混入した磁性薄膜を得ることが可能となる。

【0028】このとき、磁性金属粒子の形状磁気異方性は、磁性金属粒子が細長い柱状に成長した場合には、磁性薄膜の膜厚方向に付与されるが、結晶の成長の状態によっては、円柱状の結晶粒がその中心軸を膜面内方向に向けて成長することもある。その場合には、膜面内方向に形状磁気異方性が付与されることになる。また、結晶磁気異方性の向きは、異方性を有する結晶軸が膜厚方向／膜面内方向のどの方向に向かくによって決まる。これは、結晶成長の状態により制御することが可能である。結晶成長の状態に影響を与えるプロセスパラメータとしては、上述の投入電力、スパッタリング圧力、反応性ガス種、成膜速度、バイアス電力、添加物の種類等が挙げられる。この他にも、基板の状態や下地膜の成膜の状態、例えば結晶方位や表面エネルギー等も磁気異方性に

影響を及ぼすので、これらのパラメータを選択することによっても所定の磁気異方性を得ることができる。

【0029】また、化学的蒸着法としては、MOCVD やプラズマCVD、多元同時蒸着等が挙げられる。これらの方法において、必要に応じて基板上に堆積された材料に熱処理を施して、非磁性母材中に磁性金属粒子を析出させてよい。

【0030】磁性薄膜を基板上に形成する際に、媒体表面側で磁性金属粒子が非磁性母材に示める割合を小さくし、基板界面側でその割合を大きくすることにより、磁気ヘッドとの間の短絡をより完全に防止することができる。反対に、上記割合を媒体表面側で大きくし、基板界面側で小さくすることにより、媒体磁界強度を向上させることができる。なお、磁性金属材料のターゲットと非磁性材料のターゲットに投入するパワー比等の成膜条件を変えることにより、非磁性母材中の磁性金属粒子の割合や分布状態を選択することができる。

【0031】本発明の磁気記録媒体は、従来の磁気記録媒体に対して以下に示すような特徴を有する。

20 (1) 保護層によるスペーシングロスの解消

本発明の磁気記録媒体は、非磁性母材が高硬度の材料からなるために、磁性薄膜が充分な機械的強度を有する。このため、従来の磁気記録媒体で必須であった保護層を設ける必要がなくなる。記録・再生ヘッドと磁性薄膜との間の距離であるスペーシングは、従来は保護層の厚さ以上にしかできなかったが、本発明による磁気記録媒体では、この制限が全くなくなる。このことは、スペーシングを小さくして、従来は不可能であった高密度記録が可能になることを意味し、また、従来と同程度の記録密度とする場合には、磁気記録媒体とヘッドとの距離を大きくすることができ、ヘッドや媒体の損傷確率を大幅に低減できることを意味する。さらに、保護層を作製する工程が不要になるため、媒体作製の歩留りが向上し、媒体の製造コストを下げることができる。なお、保護層がない状態での動作に耐えるに充分な硬度を磁性薄膜が持たない場合、あるいは接触動作等の従来の保護層つきの媒体ですら耐えられないような使われ方をする場合には、本発明による磁性薄膜上に保護層を設けてよい。この場合、磁性薄膜自体の硬度は従来の金属薄膜に対して大きいので保護層は作製し易い。

30 (2) 媒体ノイズの低減

本発明の磁気記録媒体では、個々の磁性金属粒子の間に非磁性母材が存在し、磁性金属粒子間の距離が交換相互作用の及ぶ距離よりも大きいので、媒体ノイズを小さくすることができる。

【0032】情報の記録は磁気記録媒体上に反転磁区を形成することによって行われるが、この反転磁区はさらに磁性薄膜の結晶粒から構成される。結晶粒内では各原子のスピニは同じ向きを向いており、ヘッドからの磁界によって結晶粒内でほぼ同時に反転する。したがって、

反転磁区の境界の粗さは理想的には結晶粒の大きさ程度であり、この境界の粗さが情報を記録することによって生じる記録ノイズの原因となる。磁性薄膜では、一般には磁性体の結晶粒の間には酸化物等の非磁性体が存在するが、結晶粒間の距離が短く磁気的な絶縁が不充分であると結晶粒間に交換相互作用が働く。このような状態では、一つの結晶粒が磁化反転すると交換相互作用によって隣接する結晶粒も磁化反転してしまい、磁化反転の単位はいくつかの結晶粒群となる。この場合、反転磁区の境界はより粗くなり、大きな媒体ノイズが発生してしまう。従来の磁気記録媒体は、この問題に悩まされており、媒体材料にいろいろな添加物を添加することが試みられているが、結晶粒間の相互作用を完全に分断することはできない。現在までのところ、結晶粒間を 1 nm 程度にまで離すことができてはいるが、磁性元素の拡散等のために磁気的な絶縁は完全ではなく、数～数 10 dB の記録ノイズが発生している。一方、本発明の磁気記録媒体にはこの問題がない。すなわち、磁性結晶粒間が非磁性母材により完全に絶縁されているために、交換相互作用が極めて小さい。

(3) 媒体の抵抗率の制御性

高感度の磁気抵抗効果 (MR) 型ヘッドを用いる場合には、磁気記録媒体の抵抗率が問題になる。すなわち、媒体一ヘッド間の放電による記録・再生素子や媒体の破壊が問題となる場合には、磁気記録媒体の電気伝導性が高い方が好ましい。また、媒体への電流リークによる MR 素子の破壊や信号強度の低下が問題となる場合には、磁気記録媒体は絶縁性である方が好ましい。

【0033】従来の磁気記録媒体の構成は、金属薄膜上に絶縁性保護層が形成された構成であり、磁気特性や保護性能を損なわずに磁気記録媒体全体の電気抵抗率を制御することは不可能であった。ところが、本発明による磁気記録媒体は、磁性金属粒子と非磁性母材との混合物であり、両者の混合比や添加物の種類や量等で電気抵抗率を任意に制御することができる。

【0034】また、従来の金精薄膜媒体が有する上記の問題点を解決する方法として、磁性金属微粒子を誘電体中に分散してなる磁性薄膜が提案されている (U.S.P. 4,973,525)。しかしながら、この磁性薄膜は、磁気記録媒体に使用可能な磁気特性を得るためにには、700～800 K に加熱した基板上にスパッタリングにより作製する必要があることが記載されているだけで、大きな磁気異方性エネルギーをどのようにして得るのかということについて述べられていない。特に、実施例に挙げられている Fe 微粒子は結晶磁気異方性エネルギーがかなり小さい材料であることが知られており、また、形状も球形に近く、磁気記録媒体に必要な保磁力を得ることは難しい。実施例では 1 kOe 程度の保磁力が得られることが記載されているが、これは熱処理等による応力によって誘起されたものと考えられる。この場

合、応力による膜の剥離が問題となる可能性があり、また、700～800 K という熱処理温度は基板にダメージを与える可能性がある。これに対して、本発明の磁気記録媒体は、磁性金属粒子が形状磁気異方性と結晶磁気異方性の両方を有するので、大きな保磁力を得ることが可能である。また、熱処理を必要としないので基板に与えるダメージもない。

【0035】ここで、本発明の磁気記録媒体の例を図 1 および図 2 を参照して説明する。図 1 において、ガラス基板 11 上には、形状磁気異方性および結晶磁気異方性を有する磁性金属粒子 1 と膜厚方向および膜面内方向に連続して存在する非磁性母材 2 とからなる磁性薄膜が形成されている。

【0036】また図 2 において、ガラス基板 11 上には下地層 12 が形成され、さらにその上に形状磁気異方性および結晶磁気異方性を有する磁性金属粒子 1 と、膜厚方向および膜面内方向に連続して存在する非磁性母材 2 とからなる磁性薄膜が形成されている。ここで、このような磁性薄膜の厚さは 100 nm 以下、さらには 50 nm 以下、さらには 20 nm 以下であることが好ましい。これは、磁性薄膜の厚さが厚すぎると成膜時間が長時間化する上、磁性薄膜中に応力に起因する歪みが入り、膜が剥離し易くなるからである。なお、長手記録を行う場合には、薄膜であるほど高密度の記録が可能になる。

【0037】本発明の磁気記録媒体を構成する磁性薄膜は、磁性金属粒子と非磁性母材との複合材料とみなすことができる。この磁性薄膜を複合材料の connectivity の定義に従って表現すれば、非磁性母材が 3 次元に広がり、磁性金属粒子が 2 次元または 1 次元の結合状態になっていることから、いわゆる「3-1 結合」または「3-2 結合」であるといえる。このような結合状態は、従来の磁気記録媒体では知られていない。

【0038】本発明の磁気記録媒体において、非磁性母材がネットワーク状になっていることは、磁性薄膜を酸等に浸して磁性金属粒子のみを充分に溶解することにより確認できる。そして、磁性金属粒子のみを取り除いても、非磁性母材が元の磁性薄膜の形状を保った状態で基板上に残存するのであれば、磁性薄膜自体が堅牢性に対する必要条件を充分に満たしていると言える。

【0039】本発明の磁気記録媒体は、磁性金属粒子と非磁性母材とが相分離して混在している構造を有する。ただし、微視的な観点からは、薄膜形成時あるいは薄膜形成後に、磁性金属粒子を構成する原子と非磁性母材を構成する原子の拡散が起こり得るので、原子レベルで完全に磁性金属粒子と非磁性母材とが分離された複合膜を形成することは困難である。したがって、磁性金属粒子と非磁性母材とが分離された構造がもたらす上述の利点を得るためにには、非磁性母材の特定領域（中央部）において、磁性金属粒子を構成する磁性元素の含有率が 20 原子% 以下である、あるいは磁性金属粒子中央部におい

て非磁性母材を構成する元素の含有率が 20 原子%以下であることが必要である。

【0040】ここで、磁性金属粒子の中央部および非磁性母材における磁性金属粒子間の特定領域（中央部）について説明する。図3は図1に示す構成において、磁性金属粒子としてCoPt粒子を用い、非磁性母材の材料にSiOを用いた場合における微粒子分散薄膜の透過型電子顕微鏡（TEM）による薄膜平面像を示す図である。図中31は主にCoPtからなる磁性金属粒子部を示し、32は主にSiOからなる非磁性母材部を示す。これらの部分は、平面TEM像において、結晶格子の不連続部、像のコントラストの不連続変化部等によって明瞭に区別できる。

【0041】図4は図3中のA-A線上のSiとCoの組成分布を示す図である。この微細な組成分析は、電子線回折によって図3の像と同時に得ることができる。図4中には図3より判断される磁性金属粒子部31および非磁性母材部32の境界も示してある。本発明の磁気記録媒体において、非磁性母材における磁性金属粒子間の特定領域とは、図4の磁性金属粒子部31間の非磁性母材部32の領域の中央部80%の領域のことである。また、磁性金属粒子の中央部とは、図4の磁性金属粒子部31の領域の中央部80%の領域のことである。また、この領域は、平面TEM上のA-A線の選び方によって広さが異なるので、上記の分析を複数回行って、その平均値で決定する。したがって、分析平均値により、磁性金属粒子と非磁性母材との分散の度合いを評価することとなる。

【0042】図5は、図3と同様の組成で、上述の磁性金属粒子と非磁性母材の間に界面層が存在している場合の平面TEM像を示す図である。図中31は主にCoPtからなる磁性金属粒子部を示し、32は主にSiOからなる非磁性母材部を示し、51はアモルファスCoOからなる界面層を示す。図3の場合と同様に、これらの部分は、平面TEM上で明確に区別できる。また、図6は、図5のB-B線上の組成分析の結果を示す図である。図6の場合の磁性金属粒子中央部は、領域31の中央部80%の領域であり、非磁性母材における磁性金属粒子間の特定領域は、領域31間の領域32の中央部80%の領域である。

【0043】非磁性母材中の磁性金属原子は、磁性金属粒子間の交換相互作用を強める作用を持つ。図7に図3の例における非磁性母材の特定領域の磁性元素（Co）量に対する交換相互作用の減衰量を示す。これは、2つの磁性金属粒子間に非磁性母材を設置し、Co量が0原子%の場合の交換相互作用の減衰量を1としたときの相対量で示してある。図7から分かるように、Co量が5, 10, 20原子%のときに、減衰量がそれぞれ0.99, 0.97, 0.95であり、50原子%になるとほとんど減衰しなくなる。このことから、非磁性母材の

特定領域の磁性元素の許容濃度は20原子%以下、好ましくは10%以下、より好ましくは5%以下である。20原子%以上の濃度では、磁性金属粒子と非磁性母材との間での構成元素の拡散（例えば、非磁性母材中の酸素原子の磁性金属粒子内への拡散）が起こり易くなり、磁性薄膜全体の磁気特性の劣化につながってしまう。

【0044】図8には、図3の例における磁性金属粒子の中央部におけるSi量に対する磁気異方性エネルギーの変化を示す。Si量が0原子%の場合を1とした相対値で示す。図8から分かるように、Si量が5, 10, 20原子%のときに、磁気異方性エネルギーがそれぞれ0.95, 0.90, 0.80であり、20原子%以上ではCoPtの持つ磁気異方性エネルギーを充分に引き出せなくなり、磁気記録媒体としての磁気特性を維持できなくなる。このことから、磁性金属粒子中央部での非磁性母材の構成元素の許容濃度は20原子%以下、好ましくは10%以下、より好ましくは5%以下である。20原子%以上の濃度では、磁性金属粒子と非磁性母材との間での構成元素の拡散が起こり易くなり、磁性薄膜全体の磁気特性の劣化につながってしまう。なお、上記元素分析は、表面化領域で行うが、厚さ100nm以下程度の薄膜では、表面化領域における元素分析と膜厚方向における元素分析とは等価である。

【0045】本発明の磁気記録媒体において、形状磁気異方性をもつ磁性金属粒子は、球形以外の異方的な物理的形状をもつのが一般的であり、異方性を生じさせたい方向に円柱、回転楕円体などの長い棒状の形状であることが好ましい。ここで、磁性金属粒子の形状についてさらに詳細に説明する。いま、磁化Iを持つ体積vの磁性粒子について、その反磁界係数をN、真空の透磁率をμ₀、とすると、Nの方向の静磁エネルギーは、

$$U = 1 / 2 \mu_0 \cdot N \cdot I^2 \cdot v$$

で表される。磁性粒子がz軸に関して軸対称であれば、

$$x, y, z \text{ 軸方向の反磁界係数 } N_x, N_y, N_z \text{ は}$$

$$N_x = N_y = (1 - N_z) / 2$$

である。磁性粒子の形状が回転楕円体である場合を考えると、飽和磁化I_sがz軸から角度θで傾いている場合の静磁エネルギーUは、

$$U = 1 / 4 \mu_0 \cdot I_s^2 \cdot v \cdot (3N_z - 1) \cos^2 \theta + \text{const.}$$

である。この式から、形状磁気異方性エネルギーの大きさは(1-3N_z)に比例することがわかる。また、形状磁気異方性が最大になるのはN_z=0、最小になるのはN_z=1/3のときである。z軸に沿って細長の回転楕円体の（長軸の長さ）/（短軸の長さ）をrとし、rと(1-3N_z)との関係を調べると、r=1, 1.5, 2, 3, 5, 10に対してそれぞれ(1-3N_z)=0, 0.30, 0.48, 0.67, 0.83, 0.94となる。このことから、rが1.5以上であれば最大の形状磁気異方性のほぼ30%、さらにrが3以上で

あればほぼ 70 % の形状磁気異方性を得ることができる。またこれは、磁性金属粒子の形状が長い棒状であれば、回転楕円体に限らずほぼ同様の関係が満足される。

【0046】次に、本発明における磁気記録媒体を用いて高密度記録を実現するために、磁性薄膜が満たすべき条件について検討する。以下において磁性薄膜の物性のうち充填率および電気抵抗率について説明する。

(1) 充填率

$$p = 2\pi a^2 / (\sqrt{3} \cdot (2a + b)^2) \quad \cdots (1)$$

【0048】現在用いられている典型的な薄膜型磁気記録媒体の磁性金属粒子の結晶粒径は約 40 nm であり、磁性金属粒子間の交換相互作用を分断するために要する距離は少なくとも約 1 nm であることが知られている。これらの値を代入して計算すると p は 0.7 以下となる。さらに、磁性金属粒子の充填率を制御することによって、磁性金属粒子間の磁気的相互作用の分断の度合を制御できることは明らかである。より高密度の記録を行うには、充填率の値は 0.5 以下であることが好ましい。ただし、充填率の値は指針の 1 つであり、 p の最適値は磁気ドライブシステムの仕様によって決まるものである。また、本発明の磁気記録再生装置における磁気記録媒体では、磁性金属粒子を非磁性母材の不純物とみなすことができるため、充填率によって磁性薄膜の内部応力を制御することができる。なおここで、磁性金属粒子の底面から見た配列が fcc 等 hcp 以外であっても、同様の理由からこのようない充填率の値 0.7 以下で磁性金属粒子の交換相互作用は有効に分断される。以上のように磁性薄膜全体にわたる充填率の平均値を制御することもできるが、磁性薄膜の膜厚方向に沿って充填率の変化のさせ方を任意に制御して種々の特性を改善することもできる。なお、充填率の下限は特に限定しないが、0.05 以上であれば充分である。

【0049】例えば、磁性薄膜の厚さ方向に沿って充填率の高い部分と低い部分とが交互に現れるように変化させると、局所的に少しづつ応力を集中させることができ、全体として内部応力を緩和させることができる。磁性薄膜の内部応力が緩和されると、基板に対する磁性薄膜の密着性が向上するので、磁気記録媒体の耐久性、寿命が向上し、さらにバーストノイズの原因となる磁性薄膜の欠陥を減少することができる。なお、このような充填率の変化のさせ方は一例であって、磁性薄膜の成膜条件によって内部応力の値は異なるので、それぞれの場合によって適切な変化を与えるべき。

【0050】また、基板面から磁性薄膜表面に向かって充填率が低くなるように変化させると、磁気記録媒体の表面の硬度が向上するので、ヘッドクラッシュ等に対する磁気記録媒体の耐久性をより向上させることができる。この場合、ヘッドを接触走行させて記録させても十分な耐久性を有するので、非常に高密度の磁気記録が可

能性母材中における磁性金属粒子の充填率は磁性薄膜の硬度、磁気特性等に重要な影響を及ぼす。いま、磁性金属粒子が円柱形状であり、底面から見た粒子の配列が hcp であると仮定すると、充填率 p は粒子の半径 a および粒子間の間隔 b を用いて、以下の式 (1) で表される。

【0047】

【数 1】

… (1)

能な磁気記録媒体を実現できる。

【0051】逆に、基板面から磁性薄膜表面に向かって充填率が増加するように変化させると、磁性薄膜の表面における磁化が大きくなるため、再生出力を大きくさせることができる。ここで、基板と非磁性母材の材料が類似しており、両者の膨張係数などの機械的特性が類似している場合には、基板と磁性薄膜との界面における機械的特性の差が小さくなるため、密着性を向上させることができる。

【0052】さらに、磁性薄膜と磁気ヘッドとを接触させて記録する場合には、磁性薄膜の表面における硬度および電気絶縁性が高いことも重要な因子になる。したがって、磁性薄膜の表面における磁性金属粒子の割合も重要なパラメータの 1 つである。磁性薄膜の表面においては、(磁性金属粒子の面積) / (非磁性母材の面積) の値が、磁性金属粒子の充填率と同様に、0.7 以下、さらには 0.5 以下であることが好ましい。実質的には、0.05 以上あれば充分である。

(2) 電気抵抗率

【0053】本発明の磁気記録媒体では、非磁性母材として絶縁体を用いれば、磁性金属粒子の充填率を制御することによって、磁性薄膜の電気抵抗率を制御することができる。また、非磁性母材に元素を添加することにより薄膜全体の電気抵抗率を制御することができる。例えば、磁性薄膜の電気抵抗率が $1 \Omega \cdot cm$ 以上あれば、ヘッドの導体部分に比べて充分に絶縁体とみなすことができ、MR ヘッドを用いた場合でも接触時の媒体へ電流がリークすることによるヘッドの破壊を防ぐことができる。MR ヘッドのようにヘッドの導体部分が微細化されている場合には、その部分の抵抗が増加するので、磁性薄膜の電気抵抗率は $10^1 \Omega \cdot cm$ 以上であることが好ましく、さらに完全な電気絶縁性を保つためには $10^2 \Omega \cdot cm$ 以上であることが好ましい。

【0054】一方、ガラス基板上の磁性体薄膜からなるディスク状の媒体を高速に回転させると、大気との摩擦によってディスク上に電荷が発生することが知られている。ディスク上にたまつた電荷が磁気ヘッドへと放電してしまうと、ヘッド素子が破壊される可能性がある。たまつた電荷量が少くとも、磁気ヘッドの導体部分の体積が小さいと、そこに流れる電流は大きくなる。したが

って、ヘッド素子の集積化が進むにつれて、このディスク上にたまる電荷が問題となる。上記の絶縁性よりも電荷の方が問題となる場合には、媒体にある程度の導電性を付与することが好ましい。ただし、完全に導体となつてしまふと上述のヘッド素子からの電流のリークが発生するので好ましくない。具体的には、電気抵抗率は $10^{-1} \sim 10^1 \Omega \cdot \text{cm}$ であることが好ましい。なお、上記の絶縁性およびある程度の電気伝導性は、用いるヘッドや磁気ディスク装置等のシステム環境によって選択する。 $10^{-1} \Omega \cdot \text{cm}$ 以上の電気抵抗率を実現する母材材料としてはインジウム錫酸化物 (ITO) が知られている。また、 $10^{-1} \Omega \cdot \text{cm}$ 以上の電気抵抗率を実現する母材材料としては、TiN、TaN、TiC等の遷移金属の窒化物が知られている。それ以上の電気抵抗率を実現する場合には、通常の誘電体材料、例えばSiO、AlN、BN等を用いればよい。

【0054】上述の媒体の電気抵抗率に対する要求は、磁気ディスクドライブシステム上においては、ヘッドを媒体に接触させた状態で、媒体基板またはスピンドルとヘッド内のいかなる導電性部分との間においても満たされるのが好ましい。例えば、静電気によるヘッド素子の破壊を防止するのであれば、ヘッドを媒体に接触させた状態で、媒体基板またはスピンドルとヘッド内のいかなる導電性部分との間においても電気抵抗率を $1 \Omega \cdot \text{cm}$ 以上に設定すれば、いかなる動作条件下においてもヘッドの損傷が起ららない。同様に、上述のヘッド素子からの電流のリークを防止するためには、ヘッドを媒体に接触させた状態で、媒体基板またはスピンドルとヘッド内のいかなる導電性部分との間においても電気抵抗率を $10^{-1} \Omega \cdot \text{cm}$ 以上に設定することが好ましい。

(3) 磁性薄膜全体の磁気特性

本発明の磁気記録媒体が、 1Gb/in^2 以上の高密度磁気記録を可能にするためには、微小な記録磁区を安定に保持するために高い保磁力 H_c が必要である。具体的には、 2kOe 以上の H_c を有することが好ましい。さらに、 10Gb/in^2 レベルの記録密度を達成するためには、 3kOe 以上の H_c を有することが好ましい。また、ヘッド-媒体相互作用から考えると、磁気記録媒体の H_c は磁気記録ヘッドの飽和磁束密度 B_s と密接な関係がある。

【0055】図9に、記録トラック幅 $3 \mu\text{m}$ 、ギャップ長 $0.25 \mu\text{m}$ 、スペーシング $0.06 \mu\text{m}$ である場合の計算機シミュレーションによる、 B_s と磁化転移幅 (transition length) と保磁力 H_c との関係を示す。図9中の各曲線における極小値が、その B_s で記録できる最小の磁区幅、すなわち最高の記録密度を達成できる条件となる。図9の各曲線の極小値が各 B_s での最高の記録密度を達成するのに必要な最大の H_c に相当する。すなわち、 $B_s = 0.8 \text{T}$ で 2200 Oe 、 $B_s = 1.0 \text{T}$ で 2800 Oe 、 $B_s = 1.2 \text{T}$ で 3500 Oe

Oe 、 $B_s = 1.6 \text{T}$ で 4500 Oe である。この結果から、磁気記録媒体の H_c は、CGS単位系でヘッドの B_s の $1/2$ 以下、さらには $1/4$ 以下であることがより好ましい。

(4) 磁性薄膜表面の機械的構造

本発明による磁気記録媒体には、媒体の保護のため、従来の磁気記録媒体で用いられている潤滑剤を塗布してもよい。この場合、本発明における磁性薄膜においては、非磁性母材部分あるいは非磁性母材と磁性金属粒子との界面部分に存在する空隙に潤滑剤が埋め込まれて密着性が向上する利点がある。また、積極的に潤滑剤を空隙に埋め込むために、媒体作製後に研磨することによって、磁性金属粒子あるいは非磁性母材と磁性金属粒子との界面部分に選択的に空隙を形成してもよい。この空隙は、充分な密着性を発揮させるために、半径 1nm 以上、深度 2nm 以上であることが好ましい。

【0056】さらに、本発明の磁気記録媒体を用いて高密度記録を実現するために、磁性金属粒子自体が満たすべき種々の物性について検討する。

(5) 磁性金属粒子の体積

一般に磁性体が非常に小さくなると、熱ゆらぎによって磁化を一定の方向にそろえておくことができなくなることが知られている。磁気異方性エネルギー K_u を持つ体積 v の磁性体の熱ゆらぎによる磁化 I の時間変化は、

$$I(t) = I_s \cdot \exp(-t/\tau)$$

で表される。ここで、 t は時間、 I_s は最初の磁化の値であり、 τ は

$$\tau = \tau_0 \cdot \exp(v \cdot K_u / kT)$$

で表される。ここで、 τ_0 は約 10^{-10} 、 k はボルツマン定数、 T は絶対温度である。この式から、室温($T = 300 \text{K}$)において τ が実用的な記録保持時間10年を満たすための条件は、 $v \cdot K_u < 1.7 \times 10^{-11} \text{ J}$ となる。 SmCo を例にとり K_u に $9.5 \times 10^4 \text{ J/m}^3$ を代入すると、 $v = 1.8 \times 10^{-11} \text{ m}^3$ となる。したがって、この値以上の体積であれば、熱ゆらぎによる磁化の消失がなく、磁気記録媒体として好ましく用いることができる。

(6) 磁気クラスターのサイズ

磁性薄膜上には磁気ヘッドからの磁界によって磁区が形成され、これが情報の記録の1単位となる。このとき、その磁性薄膜の最小の磁区サイズが形成されるべき磁区よりも大きいと信号のS/N比が劣化し、最悪の場合再生不可能となる。最小磁区サイズは磁気記録媒体を交流消磁したときの磁気クラスターサイズで見積もることができる。 1Gb/in^2 の記録密度を達成する記録磁区の線方向の長さは 150nm であることが知られている (Murdock: IEEE Trans. Magn., Vol. 28, p. 3078, 1992)。したがって、磁気クラスターの平均の大きさをこの値より小さくすれば、 1Gb/in^2 以上の高密度記録が可能となる。ただし、実用レベルでは、磁区の短辺に

数個の磁気クラスターが入る程度でないとノイズレベルが大きくなるので、この磁気クラスターの大きさは10 nm以下、さらに50 nm以下であることが好ましい。高S/N比の再生を実現するためには、30 nm以下であることがより好ましい。

(7) 磁性金属粒子の粒径

磁性金属粒子の粒径が、磁気記録媒体を交流消磁したときの磁気クラスターのサイズと同程度あるいはそれ以上である場合、磁気記録媒体に形成される磁区の形状はヘッドからの磁界を反映することができず、再生時のノイズの原因となってしまう。この場合、磁性金属粒子の膜面内の平均粒径が交流消磁をしたときの磁気クラスターの平均サイズの1/10以下であれば、再生時のノイズを低減することができる。ここで、磁性金属粒子の膜面内の平均粒径を算出するには、例えば磁性薄膜の表面を顕微鏡で観察して複数の磁性金属粒子についてその平均径を測定し、平均すればよい。なお、磁性薄膜表面から観察した磁性金属粒子の形状が長い棒状である場合は、例えば膜表面の顕微鏡写真に1本またはそれ以上の直線を引いて、この直線が磁性金属粒子を横断する合計長さを横断した磁性金属粒子の個数で平均し、磁性金属粒子の膜面内の平均粒径を算出する。また、磁性薄膜表面から観察した磁性金属粒子の形状が楕円体であるときは、その長軸及び短軸の長さを平均することで、磁性金属粒子の膜面内の平均粒径を算出してもよい。

【0057】本発明における磁性薄膜では、磁性金属粒子の間隔は交換相互作用が働かない程度に離れているので、磁性金属粒子が磁化反転の最小単位となる。したがって、上記のような磁性金属粒子の粒径と磁気クラスターとの関係でノイズを低減する効果が得られる。この関係を通常の金属薄膜型の磁気記録媒体において、例えば結晶粒と磁気クラスターとの関係として適用しようとしても、一つの結晶粒が磁化反転の最小単位とはならないので無意味である。

(8) 磁性金属粒子間の間隔の標準偏差

前述したように、磁性金属粒子間の磁気的相互作用を分断し、高密度の磁気記録が行うことができるようには、磁性金属粒子間の距離が約1 nm以上であることが必要であるといわれている。また、この距離のばらつきが大きいと磁性薄膜全体にわたる均一な保磁力が得られず、記録磁区形状が乱れてノイズが増加するため好ましくない。これを防ぐためには、磁性金属粒子の間隔の標準偏差が1 nm以下であることが好ましい。より高密度記録を実現するためには、この標準偏差が0.5 nm以下であることがより好ましい。

【0058】

【発明の実施の形態】以下、本発明の実施の形態を図面を参照して具体的に説明する。

(第1の実施形態) 以下のようにスパッタリング法を用いて、図1に断面で示すように、ガラス基板11上に磁

性金属粒子1と非磁性母材2とからなる磁性薄膜を形成した。すなわち、CoPtおよびSi-Oターゲットを用い、1 PaのAr雰囲気中で2元同時スパッタリングを行い、50 nm厚さの磁性薄膜を成膜した。この磁性薄膜は、CoPtからなる磁性金属粒子とSi-Oからなる非磁性母材とで構成されていた。非磁性母材の組成はSiO₂に近く、この材料はバルク状態で2 GPaのビックース硬度を有する。また、この磁性薄膜を王水中に浸し、CoPtのみを選択的に溶解させたところ、非磁性母材の部分のみ元の磁性薄膜の形状を保って残存し、非磁性母材が磁性薄膜の膜厚方向および膜面内方向に連続して存在することが確認された。

【0059】上記の磁性薄膜のTEM観察を行ったところ、図5に見られるような像が観察された。また、CoPt磁性金属粒子の中央部において、非磁性母材の構成元素であるSiおよびOの含有率は5原子%以下であった。また、Si-O非磁性母材の特定領域において、磁性金属粒子を構成する磁性元素であるCoの含有率は5原子%以下であった。CoPtとSi-Oとの界面領域は、詳細な組成分析の結果Co-O相であることがわかった。これは、CoPt磁性金属粒子とSi-O非磁性母材との結合を強める作用があり、磁性薄膜全体の韌性が向上することによって磁気記録媒体としての耐久性が向上した。

【0060】この磁性薄膜の磁気特性を測定したところ、垂直磁気異方性を有し保磁力Hcは約160 kA/m(2000 Oe)、飽和磁化Isは約0.5 Wb/m²(400 G)であった。磁性薄膜をTEM観察し、CoPtの体積充填率を算出したところ、薄膜全体にわたって一様に約0.65であった。磁性金属粒子の平均体積は 4×10^{-15} m³であった。さらに、磁性薄膜表面から測定した磁性金属粒子の膜面内の平均粒径は3~4 nmで、この試料を交流消磁したときの磁気クラスターの平均径約50 nmの1/10以下であり、かつ磁性金属粒子は細長回転楕円体の形状であり、(長軸の長さ)/(短軸の長さ)は2~5、形状磁気異方性は2.1~3.2 × 10⁵ J/m³であった。また、CoPt磁性金属粒子の結晶磁気異方性を磁気トルク測定により見積もったところ、2 × 10⁵ J/m³であった。また、磁性薄膜の表面にプローブを接触させて電気抵抗率を測定したところ、約10 Ω·cmであった。

【0061】上記の磁性薄膜の特性を向上させるために、磁性金属粒子および非磁性母材に添加元素を加えた。まず、Bを添加したCoPtターゲットを用いてスパッタリングを行うことにより、磁性薄膜中の磁性金属粒子にBを添加した。このことにより、保磁力が220 kA/mに向上した。このとき、組成分析をTEM(透過電子顕微鏡)により行ったところ、非磁性母材中の平均B濃度は磁性金属粒子部における平均B濃度の1/5以下であった。一方、Taを添加したSi-Oターゲ

ットを用いてスパッタリングを行うことにより、磁性薄膜中の非磁性母材にTaを添加した。このことにより、磁性薄膜の電気伝導率が増加し、約 $10^{-1}\Omega\cdot cm$ となり、MRヘッドからの電流リークによる素子の損傷確率が減少した。このとき、組成分析をTEMにより行ったところ、磁性金属粒子部の平均Ta濃度は非磁性母材中の平均のTa濃度の1/10以下であった。また、Bを添加したCoPtターゲットとBを添加したSi-Oターゲットを用いてスパッタリングを行うことにより、磁性金属粒子と非磁性母材の両方にBを添加した。磁性金属粒子に対するBの添加により保磁力が220kA/mになった。また、非磁性母材に対するB添加により磁性薄膜全体の歪が減少し、磁気記録媒体としての耐久性が向上した。

【0062】実際に、2.5インチのディスク状ガラス基板に上記磁気薄膜を形成し、記録・再生評価を行い、スペクトルアナライザーを用いてノイズレベルの測定を行ったところ、上記のいずれの場合においてもDC消去ノイズレベルと信号の記録後のノイズレベルは同じであった。また、磁気記録ヘッド/媒体の摺動特性評価に通常用いられるCSS(Contact Start Stop)試験を行ったところ、保護膜なしの状態で50万回以上の耐久性が得られた。

(第2の実施形態) 以下のようにスパッタリング法を用いて、図1と同様にガラス基板上に磁性薄膜を形成した。すなわち、Co、FeおよびAlターゲットを用い、酸素分圧10%のAr雰囲気中で3元同時スパッタリングを行い、200nm厚さの磁性薄膜を成膜した。この磁性薄膜は、FeCoからなる磁性金属粒子とAl-Oに近い組成を有する非磁性母材とで構成されていた。この非磁性母材の材料はバルク状態では12GPaのピッカース硬度を有する。また、この磁性薄膜を王水中に浸し、FeCoのみを選択的に溶解させたところ、非磁性母材の部分のみ元の磁性薄膜の形状を保って残存し、非磁性母材が磁性薄膜の膜厚方向および膜面内方向に連続して存在することが確認された。

【0063】上記の磁性薄膜のTEM観察を行ったところ、図5に見られるような像が観察された。また、FeCo磁性金属粒子の中央部において、非磁性母材の構成元素であるAlおよびOの含有率は5原子%以下であった。また、Al-O非磁性母材の特定領域において、磁性金属粒子を構成する磁性元素であるCoおよびFeの含有率は5原子%以下であった。FeCoとAl-Oとの界面領域の組成分析を行ったところ、ごく薄いFeCo-O相が存在することがわかった。これは、FeCo磁性金属粒子とAl-O非磁性母材との結合を強める作用があり、磁性薄膜全体の韌性が向上することによって磁気記録媒体としての耐久性が向上した。

【0064】この磁性薄膜の磁気特性を測定したことろ、面内磁気異方性を有し保磁力Hcは約160kA/

m、飽和磁化Isは約1Wb/m²であった。磁性薄膜をTEM観察し、FeCoの体積充填率を算出したところ、薄膜全体にわたって一様に約0.65であった。磁性金属粒子の平均体積は $4 \times 10^{-15} m^3$ であった。さらに、磁性薄膜表面から測定した磁性金属粒子の膜面内の平均粒径は3~4nmであり、この試料を交流消磁したときの磁気クラスターの平均径約50nmの1/10以下であり、かつ磁性金属粒子は細長回転楕円体の形状であり、(長軸の長さ)/(短軸の長さ)は2~5、形状磁気異方性は5.4~8.2×10³J/m³であった。また、FeCo磁性金属粒子の結晶磁気異方性を磁気トルク測定により見積もったところ、10⁴J/m³であった。磁性薄膜の表面にプローブを接触させて電気抵抗率を測定したところ、約10Ω·cmであった。

【0065】次に、上記の3種のターゲットに加えてさらにCrターゲットを用い、酸素分圧10%のAr雰囲気中で4元同時スパッタリングを行い、20nm厚さの磁性薄膜を成膜した。この磁性薄膜は、FeCoCrからなる磁性金属粒子とAl-Oに近い組成を有するAl-O非磁性母材とで構成されていた。この場合、磁性薄膜の保磁力Hcは約180kA/mとなった。FeCoとAl-Oとの界面領域の組成分析を行ったところ、ごく薄いFeCo-O相およびCr相が存在することがわかった。これは、FeCo磁性金属粒子とAl-O非磁性母材との結合を強める作用があり、磁性薄膜全体の韌性が向上することによって磁気記録媒体としての耐久性が向上した。

【0066】また、バイアススパッタリングを行った以外は上記と同様に4元同時スパッタリングで磁性薄膜を成膜したところ、得られた磁性薄膜の保磁力は220kA/mとなった。

【0067】さらに、永久磁石により基板に対して垂直方向に平均40kA/mの磁界を印加しながら、上記と同様に4元同時スパッタリングで磁性薄膜を成膜した。得られた磁性薄膜中の磁性金属粒子の長軸はほぼ膜面に垂直な方向を向いており、垂直磁化膜が得られた。

【0068】なお、磁性金属粒子を構成する材料としてPt、Sm、Ni等、非磁性母材を形成する材料としてZr、Ti、B等、磁性金属の添加元素としてTa、W、Hf、V、In、Si、B等、反応性ガスとして窒素、有機ガスを用いた場合にも上記と同様な結果が得られる。

【0069】実際に、2.5インチのディスク状ガラス基板に上記磁気薄膜を形成し、記録・再生評価を行い、スペクトルアナライザーを用いてノイズレベルの測定を行ったところ、上記のいずれの場合においてもDC消去ノイズレベルと信号の記録後のノイズレベルは同じであった。また、磁気記録ヘッド/媒体の摺動特性評価に通常用いられるCSS試験を行ったところ、保護膜なしの状態で50万回以上の耐久性が得られた。

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(第3の実施形態) 以下のようにスパッタリング法を用いて、図2に示すように、ガラス基板11上に形成された軟磁性下地層12上に磁性金属粒子1と非磁性母材2とからなる磁性薄膜を形成した。すなわち、まず、MnBiターゲットを用いてAr雰囲気中でスパッタリングを行い、ガラス基板11上に軟磁性下地層12を形成した。次いで、MnBiとCとがモザイク状に配置されている複合ターゲットを用いて、Ar雰囲気中でスパッタリングを行い、軟磁性下地層12上に50nm厚さの磁性薄膜を成膜した。その後、堆積した磁性薄膜を400°Cで2時間アニールした。この磁性薄膜は、MnBiからなる磁性金属粒子とCからなる非磁性母材とで構成されていた。また、構造分析の結果、非磁性母材を構成するCはダイヤモンドライカーボンであることがわかった。また、この磁性薄膜を王水中に浸し、MnBiのみを選択的に溶解させたところ、非磁性母材の部分のみ元の磁性薄膜の形状を保って残存し、非磁性母材が磁性薄膜の膜厚方向および膜面内方向に連続して存在することが確認された。

【0070】上記の磁性薄膜のTEM観察を行ったところ、図3に見られるような像が観察された。また、MnBi磁性金属粒子の中央部において、非磁性母材の構成元素であるCの含有率は10原子%以下であった。また、C非磁性母材の特定領域において、磁性金属粒子を構成する磁性元素であるMnおよびBiの含有率は10原子%以下であった。

【0071】この磁性薄膜の磁気特性を測定したところ、垂直磁気異方性を有し保磁力Hcは約160kA/m、飽和磁化Isは約1Wb/m'であった。磁性薄膜をTEM観察し、MnBiの体積充填率を算出したところ、薄膜全体にわたって一様に約0.65であった。磁性金属粒子の平均体積は $4 \times 10^{-15} \text{ m}^3$ であった。さらに、磁性薄膜表面から測定した磁性金属粒子の膜面内の平均粒径は3~4nmで、この試料を交流消磁したときの磁気クラスターの平均径約50nmの1/10以下であり、かつ磁性金属粒子は細長回転楕円体の形状であり、(長軸の長さ)/(短軸の長さ)は2~5、形状磁気異方性は $1.7 \sim 2.6 \times 10^5 \text{ J/m}^3$ であった。また、MnBi磁性金属粒子の結晶磁気異方性を磁気トルク測定により見積もったところ、 $8 \times 10^5 \text{ J/m}^3$ であった。また、磁性薄膜表面での磁性金属粒子の間隔の標準偏差を測定したところ、8nmであった。

【0072】実際に、2.5インチのディスク状ガラス基板に上記磁気薄膜を形成し、記録・再生評価を行い、スペクトルアナライザーを用いてノイズレベルの測定を行ったところ、上記のいずれの場合においてもDC消去ノイズレベルと信号の記録後のノイズレベルは同じであった。また、磁気記録ヘッド/媒体の摺動特性評価に通常用いられるCSS試験を行ったところ、保護膜なしの状態で50万回以上の耐久性が得られた。

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(第4の実施形態) 以下のようにスパッタリング法を用いて、図2に示すように、ガラス基板11上に形成された非磁性下地層12上に磁性金属粒子1と非磁性母材2とからなる磁性薄膜を形成した。まず、Crターゲットを用いてAr雰囲気中でスパッタリングを行い、ガラス基板11上に非磁性下地層12を形成した。引き続きCoPt、CrTaおよびSiターゲットを用い、窒素10%分圧のAr雰囲気中で3元同時バイアススパッタリングを行い、非磁性下地層12上に磁性薄膜を成膜した。この磁性薄膜は、CoPtCrTaからなる磁性金属粒子とSi-Nからなる非磁性母材とで構成されていた。また、この磁性薄膜を王水中に浸し、CoPtCrTaのみを選択的に溶解させたところ、非磁性母材の部分のみ元の磁性薄膜の形状を保って残存し、非磁性母材が磁性薄膜の膜厚方向および膜面内方向に連続して存在することが確認された。

【0073】上記の磁性薄膜のTEM観察を行ったところ、図5に見られるような像が観察された。また、CoPtCrTa磁性金属粒子の中央部において、非磁性母材の構成元素であるSiおよびNの含有率は5原子%以下であった。また、Si-N非磁性母材の特定領域(中央部)において、磁性金属粒子を構成する磁性元素であるCoおよびPtの含有率は1原子%以下であった。また、CoPtCrTaとSi-Nとの界面領域の組成分析を行ったところ、ごく薄いCr相が存在することがわかった。これは、CoPtCrTa磁性金属粒子とSi-N非磁性母材との結合を強める作用があり、磁性薄膜全体の韌性が向上することによって磁気記録媒体としての耐久性が向上した。また、磁性金属粒子内での組成変調構造を誘起し、磁気特性、特に保磁力を向上させる作用があった。

【0074】この磁性薄膜の磁気特性を測定したところ、面内磁気異方性を有し保磁力Hcは約200kA/m、飽和磁化Isは約0.8Wb/m'であった。磁性薄膜をTEM観察し、CoPtCrTaの体積充填率を算出したところ、薄膜全体にわたって一様に約0.5であった。磁性金属粒子の平均体積は $4 \times 10^{-15} \text{ m}^3$ であった。さらに、磁性薄膜表面から測定した磁性金属粒子の膜面内の平均粒径は3~4nmであり、この試料を交流消磁したときの磁気クラスターの平均径約50nmの1/10以下であり、かつ磁性金属粒子は細長回転楕円体の形状であり、(長軸の長さ)/(短軸の長さ)は2~5、形状磁気異方性は $3.4 \sim 5.1 \times 10^5 \text{ J/m}^3$ であった。また、CoPtCrTa磁性金属粒子の結晶磁気異方性を磁気トルク測定により見積もったところ、 $2 \times 10^6 \text{ J/m}^3$ であった。

【0075】この磁気記録媒体をドライブ装置に取り付け、静止状態でヘッドを接触させ、ヘッドとスピンドルとの間の電気抵抗率を数箇所測定したところ、いずれも約 $10^{-1} \Omega \cdot \text{cm}$ 以上であった。また、このヘッドの記

録素子において、磁極部分の飽和磁束密度 B_s が 0.4 T に設定すると、保磁力 200 kA/m (2.5 kOe) では充分な記録ができず、ノイズが増加し、信号/雑音比 (S/N 比) が小さく、高密度記録ができなかつた。一方、磁極部分の飽和磁束密度 B_s が 1 T に設定すると、ノイズが減少し、S/N 比が 8 dB 増加した。

【0076】この磁性薄膜の断面構造を TEM を用いて観察したところ、表面に半径 2 nm、深さ 3 nm 程度の空隙が多数あることが確認された。この大きさは、直径数オングストローム、長さ数 nm の潤滑材分子が入り込むには充分な大きさである。

【0077】この磁性薄膜を有する磁気記録媒体に潤滑材を塗布し、ヘッドを接触状態で走行させて密着性を調べたところ、CoPtCrTa 金属薄膜からなる磁気記録媒体の場合に比べて耐久性が向上したことがわかつた。また、潤滑材塗布の前工程であるバニッシング工程の際に、磁性金属粒子の部分と非磁性母材との部分で削れ方が異なるために、これを利用してより多くより大きな空隙を表面に形成することができる。したがって、本発明の磁気記録媒体における磁性薄膜においては、膜厚方向に均一に削っていく金属薄膜媒体に比べて、潤滑材を埋め込みのための空隙を特に工程を増やすことなく容易に作ることができる利点を有している。

【0078】上記の磁性薄膜の磁気特性を向上させる目的で、CoPt、CrTa、Si-O および Si ターゲットを用い、窒素 10% 分圧の Ar 純気中で 4 元同時バイアススパッタリングを行うこと以外は同様のプロセスで、CoPtCrTa 磁性金属粒子と Si-N 非磁性母材とからなる磁性薄膜を非磁性下地層上に形成した。

【0079】この磁性薄膜の磁気特性を測定したところ、面内磁気異方性を有し、保磁力 H_c は約 220 kA/m、飽和磁化 I_s は約 0.9 Wb/m² であった。磁性薄膜の微細な領域の組成分析を TEM により行ったところ、CoPtCrTa 磁性金属粒子の中央部において、非磁性母材の構成元素である Si および N の含有率は 1 原子% 以下、O の含有率は 10 原子% 以下であった。また、Si-N 非磁性母材の中央部において、磁性金属粒子を構成する磁性元素である Co および Pt の含有率は 1 原子% 以下であった。また、CoPtCrTa 磁性金属粒子と Si-N 非磁性母材との界面領域に界面層が存在しており、この界面層は Cr と SiO_x から構成されていることがわかつた。この Cr と SiO_x は、CoPtCrTa 磁性金属粒子と Si-N 非磁性母材との結合を強める作用があり、磁性薄膜全体の韌性が向上することによって磁気記録媒体としての耐久性が向上した。また、磁性金属粒子内の組成変調構造を誘起し、構成原子の相互拡散を防止することによって、保磁力を向上させる作用がある。

【0080】非磁性 Cr 下地層の効果を調べるために、比較例として、非磁性下地層を設けずに、ガラス基板上

に磁性薄膜を形成した。この磁性薄膜は磁性金属粒子と非磁性母材とが分離された構造を有するが、磁性金属粒子の結晶性が悪く、保磁力は 80 kA/m、結晶磁気異方性は 2×10^5 J/m² であった。

【0081】上記の磁性薄膜を用いた磁気記録媒体を、浮上型のスライダーに設置した MRR ヘッドで再生を行ったところ、媒体のチャージアップによる MR 素子の静電破壊の確率が増加した。そこで、媒体の非磁性母材に導電性を付与した。まず、Si の代わりに Ti を用いること以外は前記と同様のプロセスで CoPtCrTa 磁性金属粒子と Ti-N 非磁性母材とからなる磁性薄膜をガラス基板上に形成した。この磁性薄膜を王水中に浸し、CoPtCrTa のみを選択的に溶解させたところ、非磁性母材の部分のみ元の磁性薄膜の形状を保って残存し、非磁性母材が磁性薄膜の膜厚方向および膜面内方向に連続して存在することが確認された。また、この磁性薄膜の磁気特性は、上記に示した磁性薄膜とほぼ同様であった。

【0082】この磁気記録媒体をドライブ装置に取り付け、静止状態でヘッドを接触させ、ヘッドとスピンドルとの間の電気抵抗率を数箇所測定したところ、いずれも約 5×10^{-1} Ω · cm 以上であった。この磁性薄膜を有する磁気記録媒体を用いることにより、MR ヘッドの損傷確率が減少した。

【0083】さらに、Si の代わりに In-Sn-O を用い、窒素の代わりに酸素を用いること以外は上記と同様のプロセスで CoPtCrTa 磁性金属粒子と In-Sn-O (ITO) 非磁性母材とからなる磁性薄膜をガラス基板上に形成した。この磁性薄膜を王水中に浸し、CoPtCrTa のみを選択的に溶解させたところ、非磁性母材の部分のみ元の磁性薄膜の形状を保って残存し、非磁性母材が磁性薄膜の膜厚方向および膜面内方向に連続して存在することが確認された。また、この磁性薄膜の磁気特性は、上記に示した磁性薄膜とほぼ同様であった。

【0084】この磁気記録媒体をドライブ装置に取り付け、静止状態でヘッドを接触させ、ヘッドとスピンドルとの間の電気抵抗率を数箇所測定したところ、いずれも約 10^{-1} Ω · cm 以上であった。この磁性薄膜を有する磁気記録媒体を用いることにより、MR ヘッドの損傷確率はさらに減少した。

【0085】実際に、2.5 インチのディスク状ガラス基板に上記磁気薄膜を形成し、記録・再生評価を行い、スペクトルアナライザを用いてノイズレベルの測定を行ったところ、上記のいずれの場合においても DC 消去ノイズレベルと信号の記録後のノイズレベルは同じであった。また、磁気記録ヘッド/媒体の摺動特性評価に通常用いられる CSS 試験を行ったところ、保護膜なしの状態で 50 万回以上の耐久性が得られた。

成膜するにあたり、CoPtターゲットおよびSi-Oターゲットへの投入電力比を図10に示すように3種の方法で変化させた。Aの方法は投入電力比を正弦波状に周期的に変化させる方法である。Bの方法はSi-Oへの投入電力に対するCoPtへの投入電力の比を徐々に増加させる方法である。Cの方法はSi-Oへの投入電力に対するCoPtへの投入電力の比を徐々に減少させる方法である。各方法で得られた磁性薄膜の断面をTEM観察し、膜厚方向の磁性金属粒子の充填率の変化および磁性薄膜の特性を調べた。

【0086】投入電力比をAのように変化させる方法で得られた磁性薄膜は、粘着テープを用いた剥離試験で剥離がほとんど生じなかった。一方、投入電力比を一定にして得られた磁性薄膜では、剥離が生じ易かった。この結果は、Aの方法では磁性薄膜の内部応力が緩和されることを示している。また、この磁性薄膜を王水中に浸し、CoPtのみを選択的に溶解させたところ、非磁性母材の部分のみ元の磁性薄膜の形状を保って残存し、非磁性母材が磁性薄膜の膜厚方向および膜面内方向に連続して存在することが確認された。

【0087】投入電力比をBのように変化させる方法で得られた磁性薄膜では、磁性薄膜の表面側へ向かうにつれてCoPtの充填率が大きくなつた。また、この磁性薄膜では、粘着テープによる剥離試験で剥離が全く生じなかつた。

【0088】投入電力比をCのように変化させる方法で得られた磁性薄膜では、磁性薄膜の表面側へ向かうにつれてCoPtの充填率が小さくなつた。磁性薄膜の表面にプローブを接触させて電気抵抗率を測定したところ、投入電力比を一定にして得られた磁性薄膜の電気抵抗率の約80%となつた。

【0089】なお、ガラス基板上に磁性薄膜を成膜する前に逆スパッタリングを行うと、磁性薄膜の密着性が向上することが認められた。例えば、投入電力比を一定にして得られた磁性薄膜でも、剥離試験による剥離率が低下した。また、磁性薄膜の保磁力は160kA/mから200kA/mへ増加した。これらの効果は、スパッタエッチング処理の際に、Arイオンがガラス基板に照射されることにより、基板表面の粗さが変化し、また、基板表面の浮遊酸素が消失したことにより発揮されたものである。なお、スパッタエッチング処理以外の表面改質法、例えば、中性子線照射やイオンプレーティングによ

っても同様の効果が得られる。

【0090】実際に、2.5インチのディスク状ガラス基板に上記磁気薄膜を形成し、記録・再生評価を行い、スペクトルアナライザを用いてノイズレベルの測定を行ったところ、上記のいずれの場合においてもDC消去ノイズレベルと信号の記録後のノイズレベルは同じであった。また、磁気記録ヘッド／媒体の摺動特性評価に通常用いられるCSS試験を行ったところ、保護膜なしの状態で50万回以上の耐久性が得られた。

10 【0091】

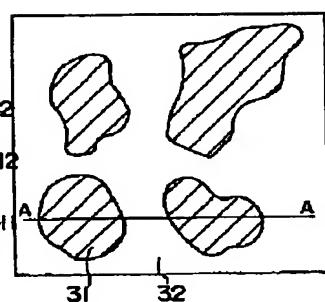
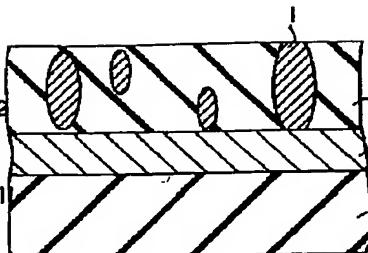
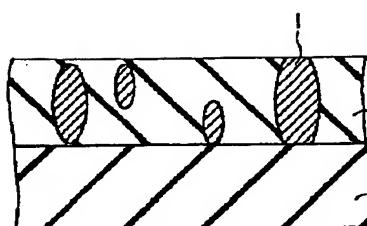
【発明の効果】以上説明した如く本発明の磁気記録媒体は、磁性金属粒子と非磁性母材とから構成される磁性薄膜を有し、非磁性母材の硬度が磁性金属粒子の硬度よりも大きく、磁性金属粒子が形状磁気異方性および結晶磁気異方性を有しており、非磁性母材における磁性金属粒子間の中央部の磁性金属元素の含有率が20原子%以下であるので、高密度記録が可能なものである。

【図面の簡単な説明】

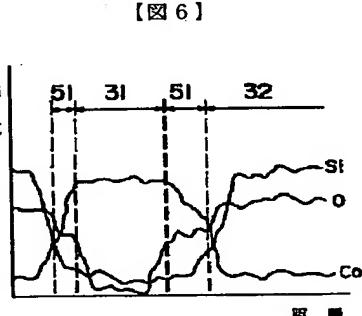
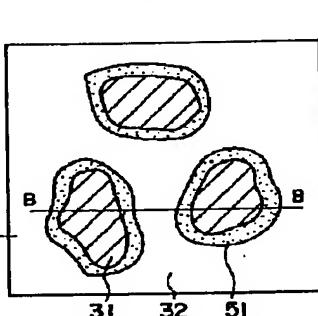
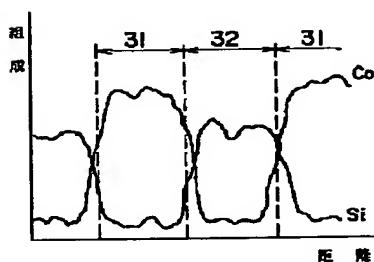
- 【図1】本発明の磁気記録媒体の一例を示す断面図。
- 【図2】本発明の磁気記録媒体の他の例を示す断面図。
- 【図3】本発明の磁気記録媒体の透過型電子顕微鏡による平面観察像を示す図。
- 【図4】図3におけるA-A線上の組成分布を示す図。
- 【図5】本発明の磁気記録媒体の透過型電子顕微鏡による平面観察像を示す図。
- 【図6】図5におけるB-B線上の組成分布を示す図。
- 【図7】本発明の磁気記録媒体の非磁性母材における磁性金属粒子間の中央部のCo量と交換相互作用の減衰量との関係を示すグラフ。

- 30 【図8】本発明の磁気記録媒体の非磁性母材における磁性金属粒子間の中央部のSi量と磁気異方性エネルギーとの関係を示すグラフ。
- 【図9】記録ヘッドの磁極部分の飽和磁束密度と磁気記録媒体の保磁力の関係を示すグラフ。
- 【図10】本発明の第5の実施形態において磁性薄膜の成膜時のCoPtターゲットおよびSiOターゲットへの投入電力比の変化の方法を説明する図。
- 【符号の説明】
1…磁性金属粒子、2…非磁性母材、11…ガラス基板、12…軟磁性下地層、31…磁性金属粒子部、32…非磁性母材部、51…界面層。

【図 1】



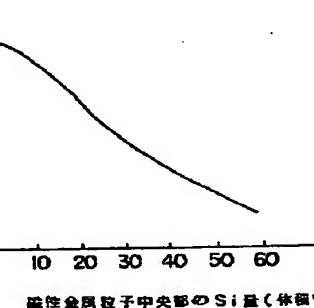
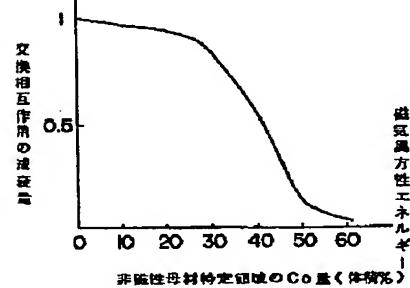
【図 4】



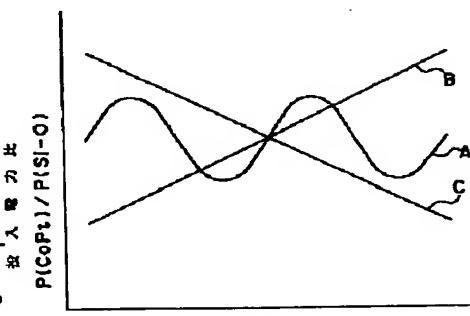
【図 7】

【図 5】

【図 6】



【図 10】



【図 9】

